FINAL REPORT

INVESTIGATION
OF REINFORCED THERMOPLASTICS
FOR NAVAL AIRCRAFT
STRUCTURAL APPLICATIONS

CONTRACT N00019-72-C-0526

by

J. T. HOGGATT

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Prepared for

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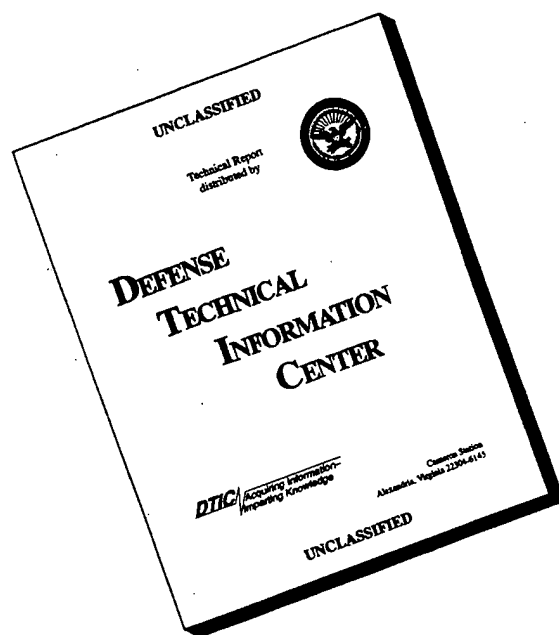WASHINGTON, D. C. 20360

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FOREWORD

This is the final report on the work conducted by The Boeing Aerospace Company during the period of June 1, 1972 to May 1, 1973 for the Naval Air Systems Command, United States Depaetment of the Navy under contract No. N00019-72-C-0526, entitled, "Investigation of Reinforced Thermoplastics for Naval Aircraft Structural Applications."   Mr. Maxwell Stander (Air 52032D) was the program monitor.

The program was conducted in the Structures/Mechanical Engineering Department of The Boeing Aerospace Company, Seattle, Washington. Dr. R. G. Cheatham was Program Supervisor and Mr. J. T. Hoggatt was Program Manager and Principal Investigator. A major participant in the program was Mr. A. D. VonVolkli.

206 655 308 /

TABLE OF CONTENTS

LIST OF FIGURES

List of Figures (Continued)

List of Figures (Continued)

LIST OF TABLES

List of Tables (Continued)

1.0   INTRODUCTION AND SUMMARY

Thermoplastic resins have been used extensively in industry primarily in unreinforced molded assemblies or reinforced with chopped glass fibers or mat; both are considered essentially non-structural or secondary structural applications. The thermoplastics are selected for these applications for their low cost, ease of formability and processability and good environmental resistance. Their entrance into the structural composite field had been hampered by their low heat distortion temperature, low mechanical properties and poor creep characteristics. In recent years, however, the development of several new thermoplastic resins has minimized these disadvantages, while retaining the processability and other favorable attributes.

Preliminary work by Boeing (Ref. 1) indicates that structural glass fabric laminates could be fabricated with thermoplastic resins which were competitive in mechanical properties with thermosetting resin laminates. This program was initiated to investigate this potential in further depth, exploring the environmental resistance, electrical characteristics and dynamic behavior in addition to the mechanical properties. The intent of this program was not to fully develop and characterize a given system but rather to demonstrate the feasibility and cost savings aspects of the thermoplastic matrix concept.

Basic savings with the reinforced thermoplastic materials result from post-forming capability, fewer production operations, ease of damage repair, ease of bonding, amenability to lower cost and more reliable quality assurance procedures, and re-processing capability, thereby, reducing scrappage. These items were investigated or assessed in this program and are discussed herein.

The program was conducted in three phases. Phase I, which constituted the major portion of the effort, concentrated on studying glass fabric reinforced thermoplastic laminates. Phase II investigated the practicality of using unidirectional graphite reinforcement rather than the glass fabric and finally, Phase III investigated potential methods of production and the cost impact of this concept on component manufacture.

1.0   (Continued)

In Phase I it was shown that glass fabric reinforced thermoplastic could perform
competitively with the standard epoxy glass fabric laminates being used in todays
aircraft components. The materials were compared on a basis of mechanical pro-
perties, environmental resistance and electrical properties. The tests included
creep, fatigue and impact tests. None of the tests conducted, although limited
in statistical depth, showed deficiencies which would preclude their use in air-
craft structure.

The polysulfone polymer, (P 1700), exhibits a possible service temperature of 300° F,
while the phenoxy polymer (PKHS-1) appears satisfactory for 165°F service.

Processing studies showed that the thermoplastic materials could result in substantial
manufacturing cost savings through reduced processing time, lower scrappage rate
and material savings. Both the glass and graphite laminates used in this program
could be readily heat-formed into structural shapes with no damage to the composite.
Radii of 1xT were formed in 90° bends with no apparent difficulties.

Preliminary mechanical property studies with grahite fiber reinforced thermoplastics
demonstrated that good mechanical properties can be achieved. With additional
processing optimization studies, properties equivalent to the epoxy systems appear
reasonable.

2

2.0   TEST PROGRAM

2.1   PHASE I - GLASS FABRIC REINFORCED THERMOPLASTIC COMPOSITE EVALUATION

2.1.1   MATERIAL SELECTION

In selecting the resin matrices to be used on this program, a survey was made of industry of the available thermoplastic resins which would possibly be suited for structural laminates. A list of requirements were established for the resins and these are tabulated in Table I. Table 2 summarizes the classes of thermoplastics reviewed. Within each of the polymer catagories shown, there are many different variations and/or polymer blends. Since this program was more concerned with proving concept feasibility rather than material optimization, no attempt was made of exhaustively screening all candidates. After reviewing data and processing characteristics of the polymers, seven candidate systems were chosen for preliminary screening (See Table 2). From these seven polymers, polysulfone (P-1700) and phenoxy (PKHS-1) both from the Union Carbide Corporation, were selected. The P-1700 was chosen for +300° F to +350° F service, while the PKHS-1 was chosen for +180° F service. It was desired to have two systems with different processing temperatures rather than two with very similar processing and service temperatures in order to gain additional processing knowledge on thermoplastics. Both systems met all the established requirements, especially impregnating qualities, compatibility, melt viscosity, and cost.

The polyimides shown gave laminates with a rather high percentage of voids and the laminate exhibites rather low peel strengths. Cost considerations eliminated the Polymer 380 and the thermoplastic polyphenylquinoxalines.

The properties of the selected polymers are shown in Table 3 and their chemical structure shown below:

Polysulfone

3
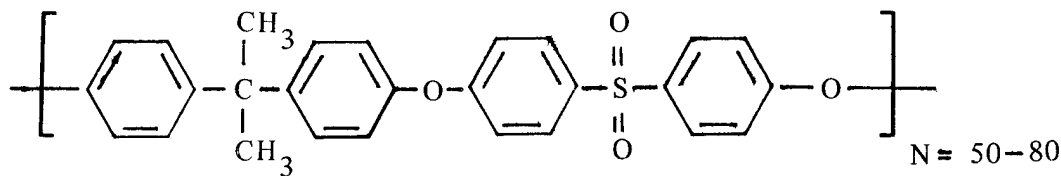
TABLE 1   RESIN SCREENING CRITERIA

Properties

1. Good mechanical properties (tension, compression)
2. Low creep
3. Good impact strength
4 Good electrical properties (no metallic fillers)
5. Good chemical resistance
6. Good heat resistance (stable properties up to its heat distortion point)
7. High adhesive strength
8. Good environmental resistance

Processing Attributes

1. Low melt viscosity and narrow melt point
2. Laminating temperature requirement − + 700°F max.
3. Laminating pressure requirement − 200 psi max.
4. Readily soluble in a selective solvent (or suitable for fabric pre-impregnation by other means)
5. Good fiber wetting qualities

Other

1. Must be commercially available in quantity
2. Must be relatively low cost

4

TABLE 2 CLASSES OF THERMOPLASTIC POLYMERS REVIEWED

Acrylonitrile-Butadiene-Styrene (ABS)
Acetals
Acrylics
Fluorocarbons
Noryl
Nylons
Phenoxy   (2 candidates)
Polyallomers
Polycarbonate
Polyether, Chlorinated
Polyethylene
Polyimide   (3 candidates)
Polyphenylene Oxide
Polyphenylene Sulfide
Polyphenylquinoxaline
Polypropylene
Polysulfone   (2 candidates)
Polyvinyl Chloride, Rigid
Styrene-Acrylonitrile

FINAL CANDIDATES

Polysulfone	P-1700 Series*	Union Carbide
Polysulfone	Polymer 360	3M Corporation
Phenoxy	PKHS	Union Carbide
Phenoxy	PKHS-1*	Union Carbide
Polyimide	Sablon 1010	Solar Corporation
Polyimide	Sablon 055	Solar Corporation
Polyimide	66-1-2	Solar Corporation

*Final Selection

TABLE 3	TYPICAL PROPERTIES OF POLYSULFONE AND PHENOXY THERMOPLASTIC POLYMERS	
Property	P-1700	PKHS-1
General		
Density	1.24	1.32
Mechanical		
Tensile Strength at Yield, psi	10,200	9,000
Tensile Modulus, psi	360,000	400,000
Tensile Elongation at Break, %	50–100	50–60
Flexural Strength, psi	15,400	14,500
Flexural Modulus, psi	390,000	400,000
Izod Impact at 72°F, ft-lb/in. notch	1.3	2–5
Rockwell Hardness	R120	R123
Thermal		
Heat Distortion Temperature at 264 psi, $^\circ$F	345	175
Coefficient of Linear Thermal Expansion, in/in/$^\circ$F	3.1×10^{-5}	$3.0–3.5 \times 10^{-5}$
Thermal Conductivity, BTU/hr/ft^2/$^\circ$F/in	1.8	—
Flammability	Non-Burning	Self-Extinguishing
Electrical		
Dielectric Strength, V/mil	425	505
Volume Resistivity, 72°F, ohm-cm	5×10^{16}	2.75×10^{16}
Dielectric Constant, 72°F, 60 Hz – 1 MHz	3.07–3.03	4.1
Dissipation Factor, 72°F, 60 Hz – 1 MHz	.0008–.0034	.0009–.001
Source	Ref. 4	Ref. 3

2.1.1   (Continued)

$$\left[O - \underset{}{\bigcirc} - \underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}} - \underset{}{\bigcirc} - O - \underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}} - \underset{\underset{OH}{|}}{\overset{\overset{H}{|}}{C}} - \underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}} \right]_{N \simeq 100}$$
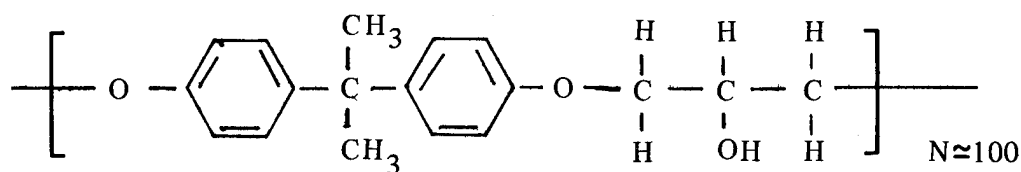
PHENOXY

The polysulfone was purchased in pellet form while the phenoxy was received as 40% solid solution in methyl ethyl ketone with a viscosity of 3200 to 4500 cps.

To provide a basis for judgement and quality, a standard epoxy thermosetting glass fabric laminate material was tested in this program along with the thermoplastic materials. The system selected as a control was Narmco 551-181 glass fabric epoxy prepreg per Boeing Material Specification, BMS 8-79. Narmco 551-181 is a material used extensively in the aerospace field and one which has a long history of successful flight service. Because of its successful use as a structural material on commercial and military aircraft, it was believed to be an excellent material for data comparison. If the thermoplastic laminates could equal the properties of Narmco 551 in its mechanical, electrical and environmental resistance properties, they should be equally qualified for aircraft service.

2.1.2   PROCESSING STUDIES

2.1.2.1   Fabric Impregnation and Laminate Fabrication

The phenoxy resin, PKHS-1, was purchased as a 40% solids solution in methyl ethyl ketone (MEK) and was used in the "as-received" condition. The P-1700 resin was purchased in pellet form and made into solution. Several solvents were tried in an attempt to obtain a solution that would be compatible with the intended impregnation technique. After screening several solvents, two solvents, methyl chloride (M.C.) and a mixture of toluene/acetone/cyclic hexanone (65/25/10% by volume) were found satisfactory. The properties desired in a solvent were:

7

2.1.2.1   (Continued)

1.   Good solubility of P-1700

2.   Low viscosity at 40-50% by wt P-1700

3.   Moderate drying rate at +70°F, rapid evaporation at +150°F.

4.   Minimum residual solvent after drying.

The methyl chloride was the final selection.

Due to the qualities of materials required and the number of variables evaluated, all impregnation was accomplished by hand on a batch-to-batch basis. For both systems the fabric was impregnated with the resin solution; permitted to air dry and then dried further in an air circulating oven at +200°F for 24 hours or until constant weight was obtained. Resin content of the prepreg was determined by weighing the glass fabric before and after impregnation. Additional resin would be added in a second impregnation set if the material was low in resin content. The general flexibility of the thermoplastic prepreg is shown in Figure 1. The PKHS and the P-1700 prepreg fabric had similar appearances and handling qualities.

The laminates were made in a press with heated platens both top and bottom. The prepreg was stacked between two titanium caul sheets (.020" thick) and these then placed between two 1/2" thick steel platens. The steel platens were then placed in a preheated press, pressure applied, and then allowed to rise to temperature. The press was preheated to +700°F for the P-1700 and to +550°F for the PKHS material. These temperatures were established in previous Boeing work (Reference 1). Pressures of 200 psi and 100 psi were used for the P-1700 and PKHS-1, respectively, unless otherwise noted.

A 200 psi maximum pressure was established so that the technology gained in the press laminate development could be translated to standard autoclave capabilities.

After the part reached the desired temperature, a 10+ 5 minute hold at temperature was made. The part was then cooled under pressure at a rate of about 5°/minute. The parts were removed from the press when the temperature fell below the heat distortion point of the matrix. This was +300°F and +180° in case of the P-1700 and PKHS-1 materials, respectively.
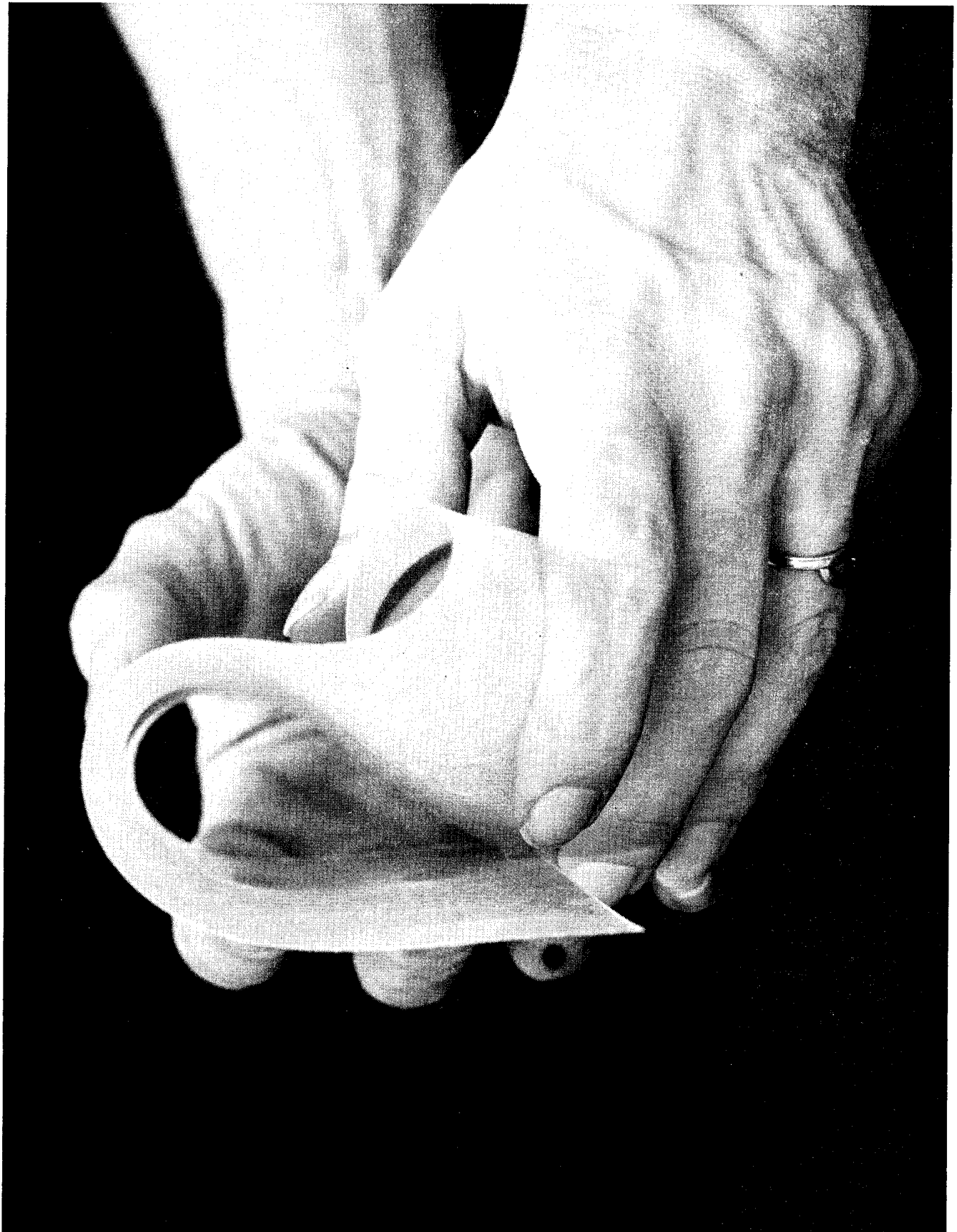
FIGURE 1   POLYSULFONE (P1700) / GLASS FABRIC PREPREG

9

2.1.2.1   (Continued)

The thermoplastic matrix materials are amenable to a wide variation in rise and
cooling rates used, and the specific rates would depend more upon the type and
capability of the equipment used in the lamination process.

2.1.2.2   Finish Study

A study was conducted to determine the best glass finish to use with the poly-
sulfone and phenoxy resins for compatibility. Three finishes (Volan, Garan and
112) on 181 style glass fabric were evaluated with each system, and the results are
shown in Table 4. The resin contents of the laminates were made intentionally high,
at about +48%, so that the matrix rather than the glass would have a predominate
effect on the composite properties, thereby making small differences in resin/glass
compatibility more apparent. With the high resin content of the prepreg, there
was some variation in the resin content of the final laminate due to resin flow and
flash.

Laminates of each material and finish were tested at +70° F in the dry and wet
(2 hour water boil) condition. The Volan-A finish gave the best overall performance
and was selected for continued use in this program.

2.1.2.3   Resin Content Evaluation

Glass fabric composite laminates of nominally $25 \pm 2\%$, $32 \pm 3\%$, $42 \pm 3\%$ and
$55 \pm 3\%$ resin by weight were fabricated and tested to determine the effect of resin
content on composite properties. A specific item of interest was to establish the
resin content level at which the best compromise in properties would be obtained.
Figures 2, 3 and 4 show plot of flexural strength, flexural modulus and interlaminar
shear strength as a function of resin content. All tests were conducted at +70° F.

Based on these tests, the properties of the reinforced thermoplastic laminates appear
to vary linearly with resin content when the resin content is greater than 32% by
weight. Between 25% and 32% resin content by weight, the properties of the

TABLE 4   FABRIC FINISH STUDY -- 181 STYLE GLASS FABRIC LAMINATES

Resin	Fabric Finish	Laminate Resin Content % by Wt.	Flexural Str., 10^3 psi		Flexural Mod., 10^6 psi		ILS., psi	
			Dry	Wet*	Dry	Wet*	Dry	Wet*
PKHS-1	Volan-A	62.4	51.0	N.C.	2.16	-1%	4650	N.C.
	Garan	48.6	44.6	-5%	2.40	-3%	5770	-6%
	112	52.0	43.9	N.C.	2.37	-2%	4680	-4%
P-1700	Volan-A	44.4	56.7	N.C.	2.60	N.C.	6040	+1%
	Garan	34.7	50.1	-3%	2.90	-8%	5420	-3%
	112	43.2	31.8	-10%	2.29	-5%	3170	-5%

N.C. = No Change

*Tested After 2-hour water boil exposure

11

FIGURE 2   EFFECT OF RESIN CONTENT ON THE FLEXURAL
STRENGTH OF 181 GLASS FABRIC LAMINATES
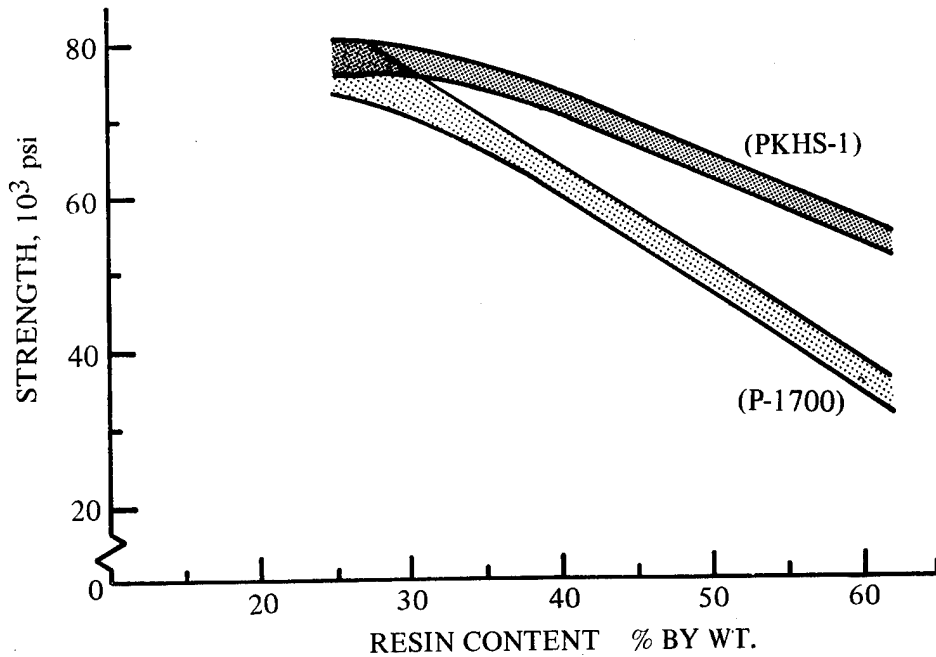
FIGURE 3   EFFECT OF RESIN CONTENT ON THE FLEXURAL
MODULUS OF 181 GLASS FABRIC LAMINATES
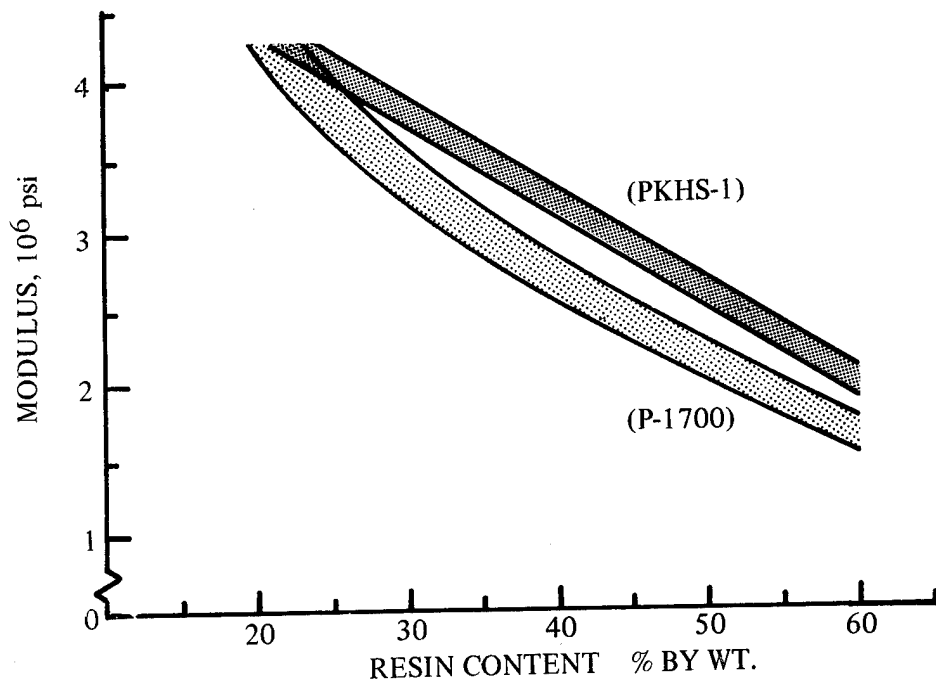
FIGURE 4   EFFECT OF RESIN CONTENT ON THE ILS STRENGTH
OF 181 GLASS FABRIC LAMINATES
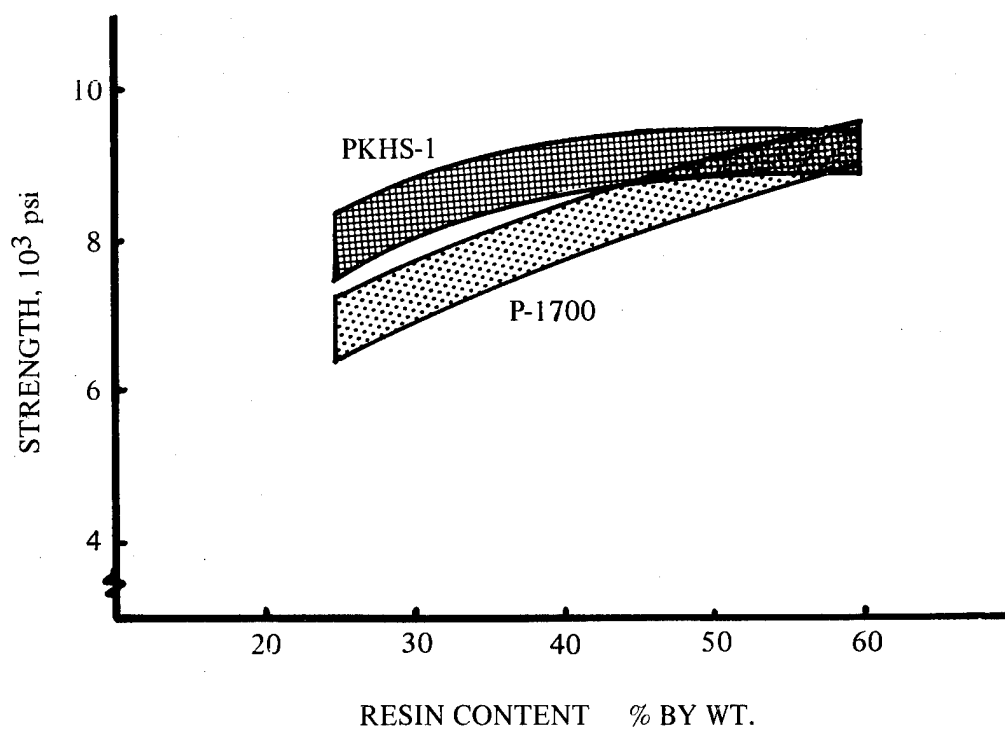
2.1.2.3   (Continued)

laminates seem to have little variation, indicating that this may be the optimum
range of resin content for these materials. Consequently, a nominal value of
28% ± 3% by weight was selected as the resin content that would be used in this
program for the feasibility studies. A cross-section of a P-1700/181 glass fabric
laminate with a 28% resin content is shown in Figure 5.

2.1.3   MECHANICAL PROPERTY TESTS

Mechanical property tests were conducted on P-1700/181 glass fabric laminates
at -65°F, +70°F and +350°F. Similar tests were performed on PKHS-1/181 glass
fabric laminates at -65°F, +70°F and +180°F. Epoxy laminate control tests were
conducted at each of the four test temperatures. All tests were 10 minute exposure
at temperature and tested at temperature unless otherwise noted.

2.1.3.1   Tensile Properties

The tensile properties of P-1700 and PKHS-1 glass fabric laminates are shown in
Figures 6 and 7. From -65 to +180°F the two thermoplastic laminates and the epoxy
controls have very similar strength and modulus properties. Between +180°F and +350°F
the P-1700 laminate showed little reduction in strength and no reduction in modulus.
This was as expected because of the thermal resistance of the polysulfone polymer
(Ref. 4). The epoxy controls drop off in both strength and modulus above +200°F
since the material is not a high temperature epoxy system. To provide a valid
comparison for the P-1700 laminates in the higher temperature range, a series of high
temperature epoxy laminates were prepared and tested. As shown in Figure 8, the
polysulfone and phenoxy laminates compare favorably to the eight epoxy laminate
materials. At +300°F the polysulfone (P-1700) is equivalent in tensile strength to the
seven high temperature epoxy systems shown.

A typical stress-strain curve for each material is shown in Figure 9. It is signifi-
cant to note that the thermoplastic laminates have both a more linear stress-strain
behavior and less total elongation than the epoxy control. As shown previously
in Figure 7, the modulus of the thermoplastic laminates do not change over the
temperature spectrum in which they were tested.

14
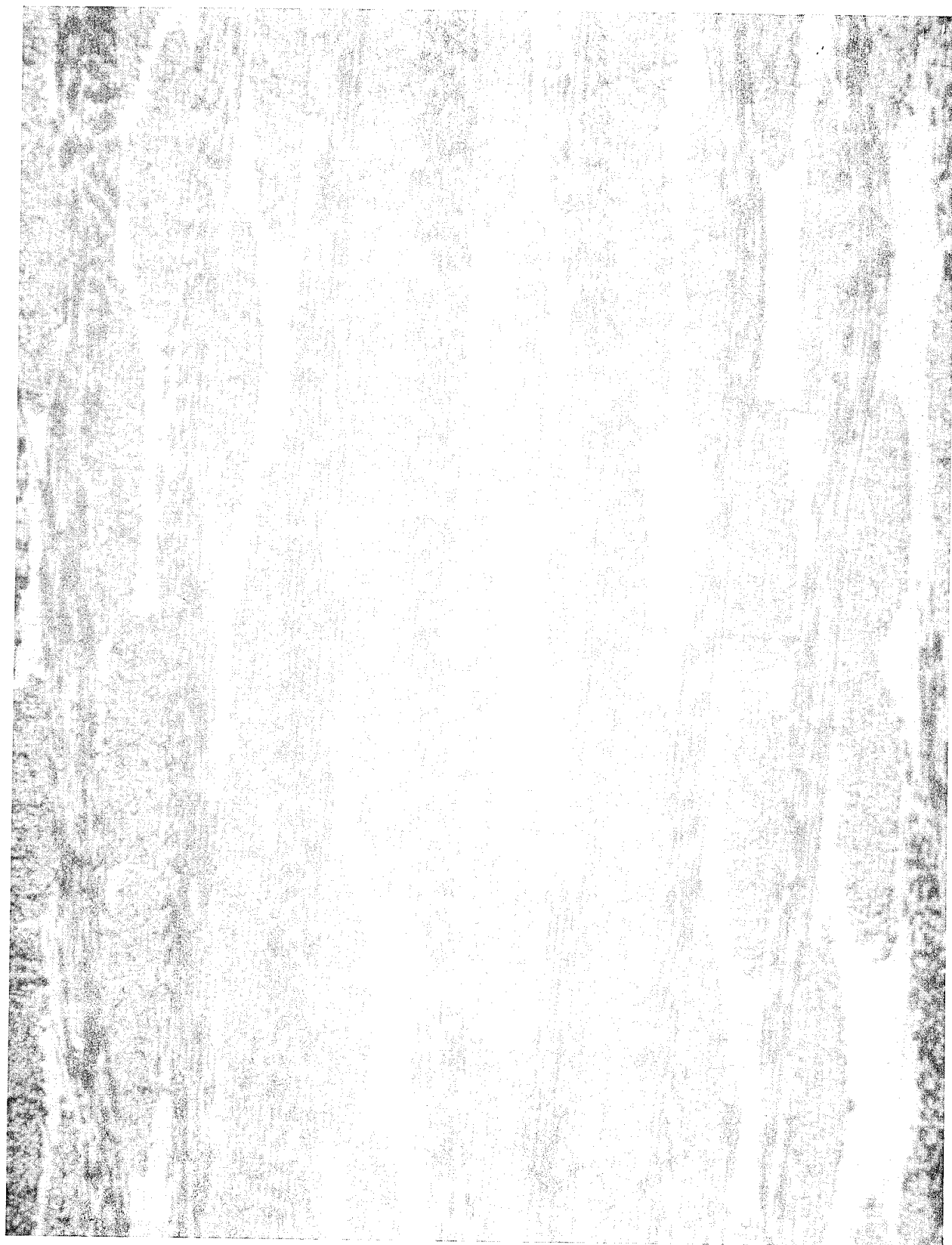
Figure 5: Cross Section of P-1700/181 Glass Fabric Laminate (65X)
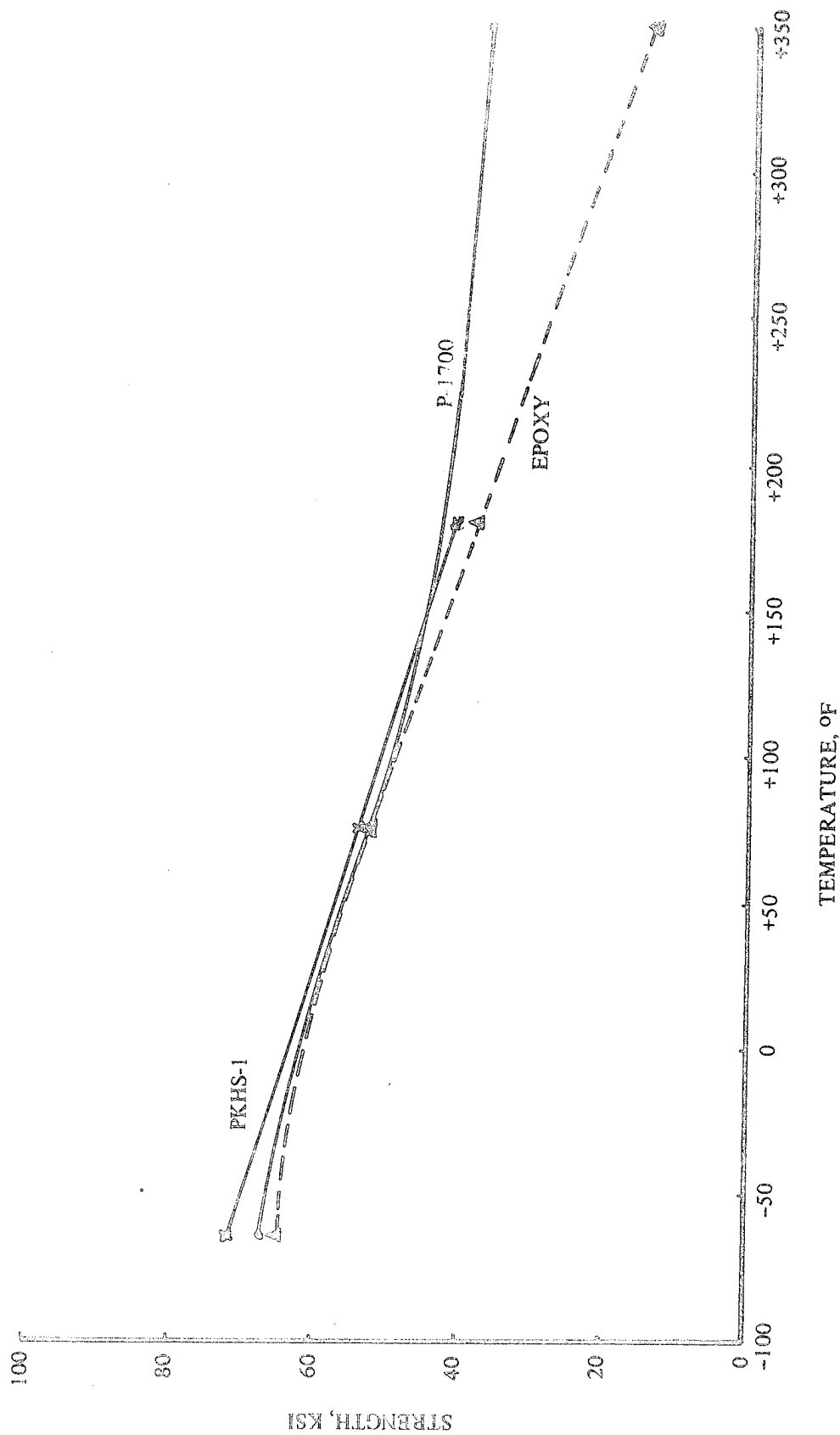
FIGURE 6   TENSILE STRENGTH VS TEMPERATURE OF 181 GLASS FABRIC LAMINATES

16
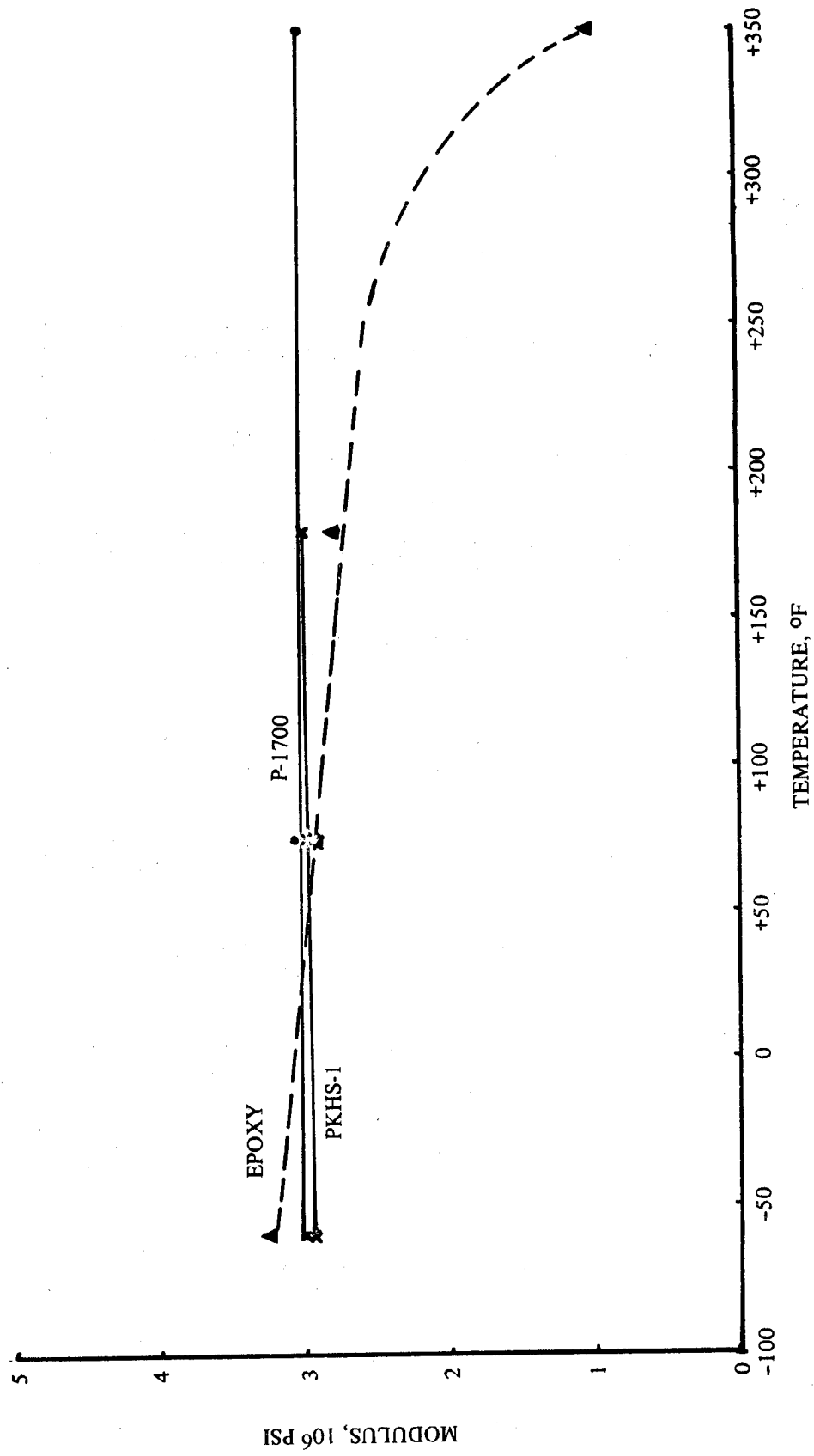
FIGURE 7   TENSILE MODULUS VS TEMPERATURE OF 181 GLASS FABRIC LAMINATES

17
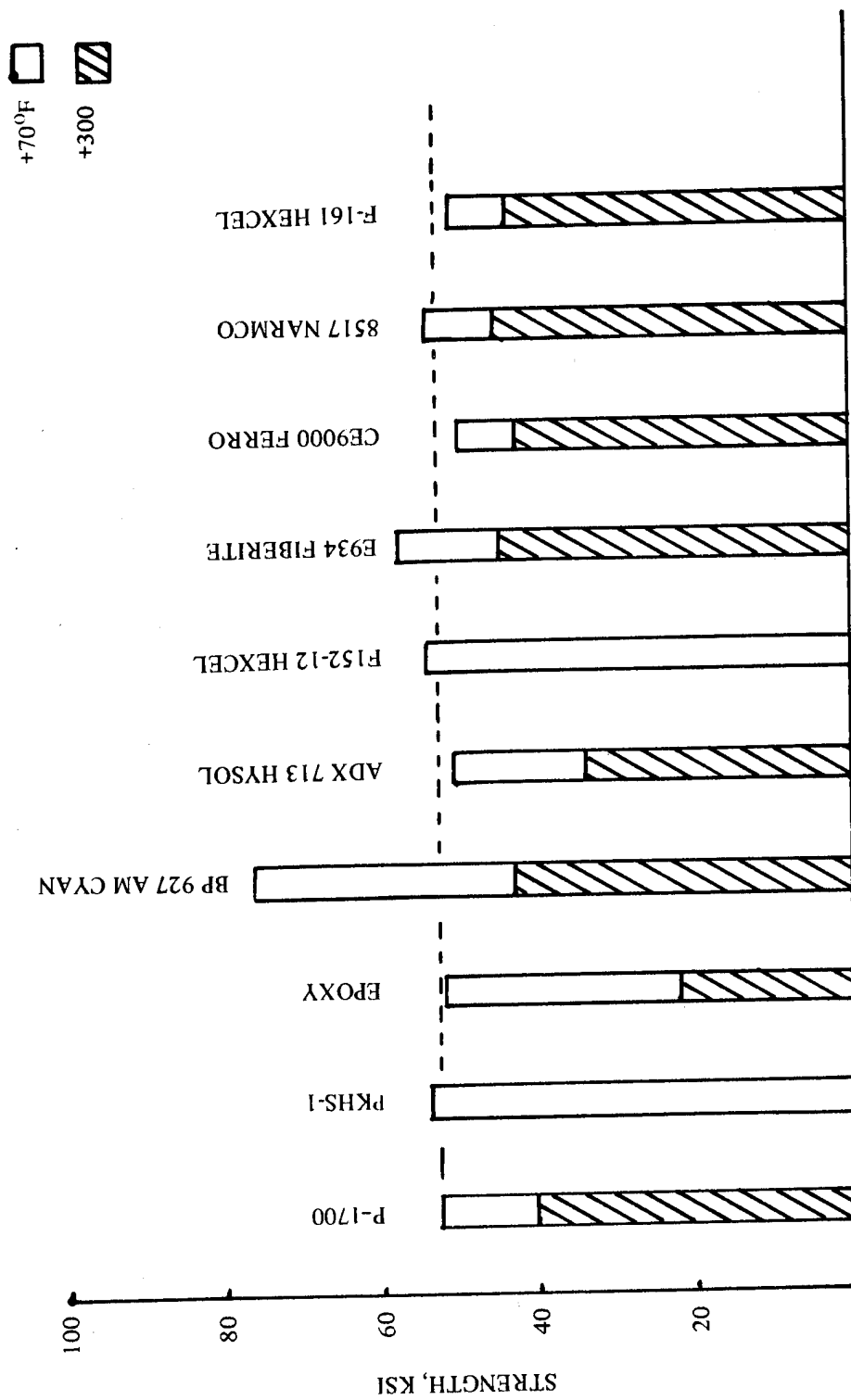
FIGURE 8   COMPARISON OF TENSILE PROPERTIES OF 181 GLASS FABRIC LAMINATES

18

STRAIN , Inches per inch

STRESS , 10^3 psi

PHENOXY (PKHS-1)

POLYSULFONE (P-1700)

EPOXY (CONTROL)

.004
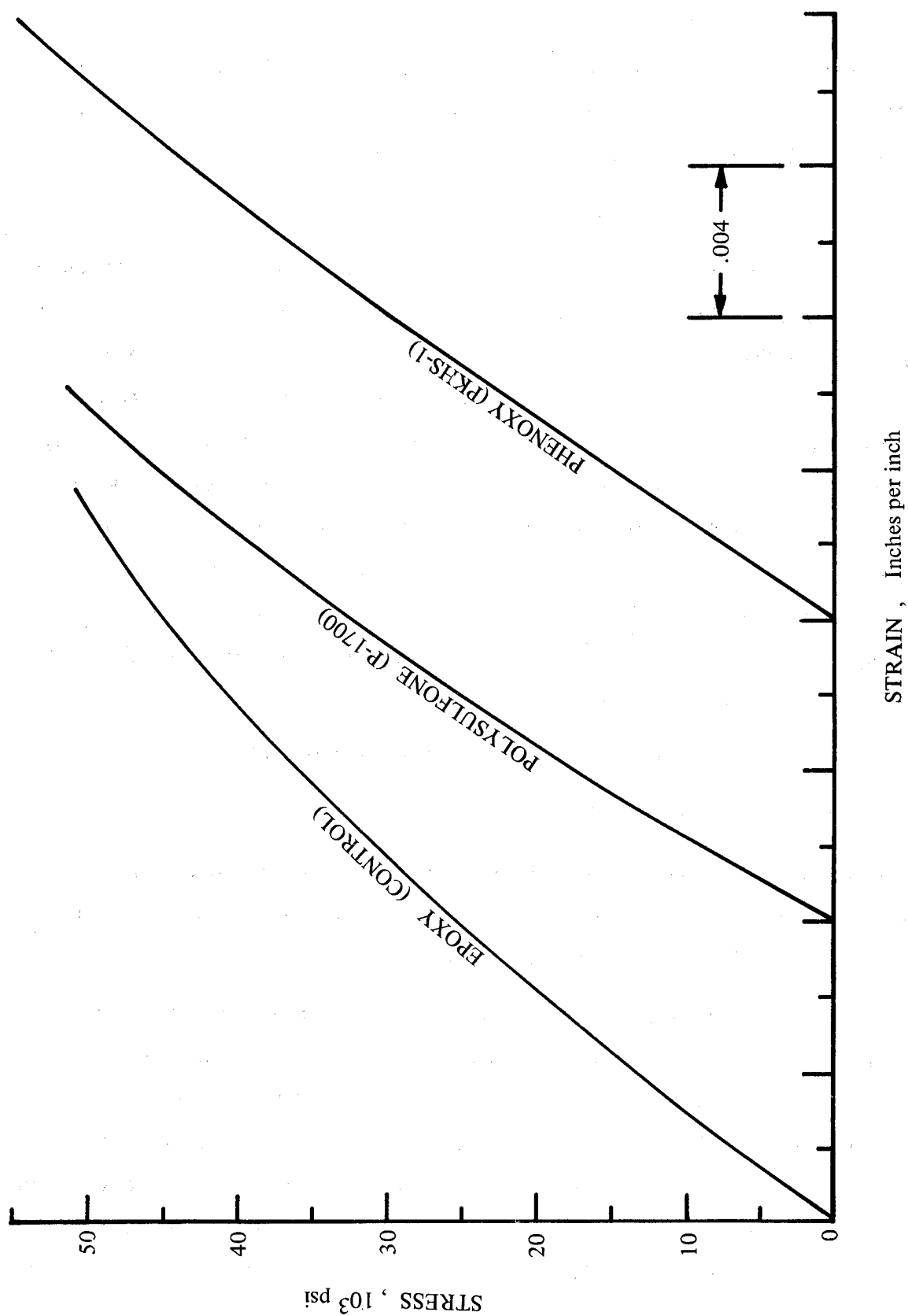
FIGURE 9 TYPICAL STRESS-STRAIN CURVE FOR 181 GLASS FABRIC LAMINATES

19

2.1.3.1   (Continued)

All tensile tests were conducted per Federal Specification L-P-406 Test Method 1011. Figure 10 shows fractured tensile specimens of each material to illustrate that the mode of failure in all the materials was the same.

2.1.3.2   Compression Properties

The compression strength vs. temperature and the compression modulus vs. temperature are shown in Figures 11 and 12, respectively, for the three laminate materials tested. Both thermoplastic laminate materials equaled or exceeded the epoxy control laminate through the entire temperature range. The P-1700 showed essentially a linear reduction in compression strength with increasing temperature, while the modulus values showed little change. A similar trend was noted with the PKHS-1 laminates. Neither thermoplastic laminate exhibited a data trend which was significantly different from the epoxy system. This was an important observation since the matrix plays a dominate role in the compression results, and if any plastic behavior was to be noted, it would most likely have been observed here. Fractured specimens are shown in Figure 13.

The compression tests were conducted per ASTM Test Method D 695-63T

2.1.3.3   Flexural Properties

The flexural strength and modulus of the thermoplastic laminates are shown graphically in Figures 14 and 15, respectively. Tests were conducted per Federal Specification L-P-406 Test Method 1031-1.

The flexural strength of P-1700 laminate was equivalent to that of the epoxy laminate over the entire temperature range of -65° F to +350° F. Both materials, however, showed degradation or plastic deformation at +350° F. The data trend between +180° F and +350° F as shown in Figures 14 and 15 are only estimates since no actual tests were conducted in between data points but the value for P-1700 at +300° F is believed to be higher than shown based on the properties of the polymer at that temperature. (The value at +180° F for the P-1700 is an acutal data point).

20
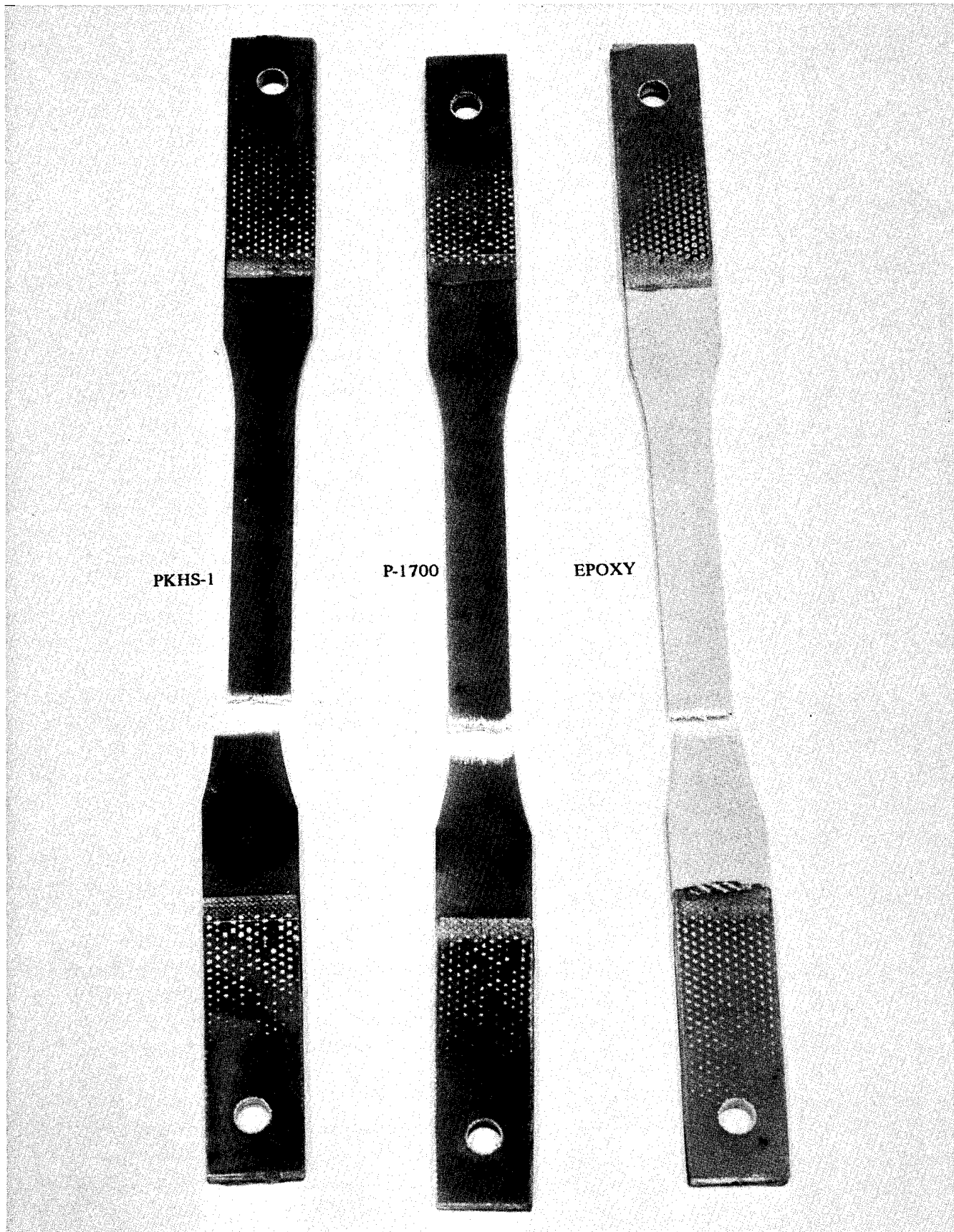
FIGURE 10 TYPICAL FAILURES – TENSION SPECIMENS

21
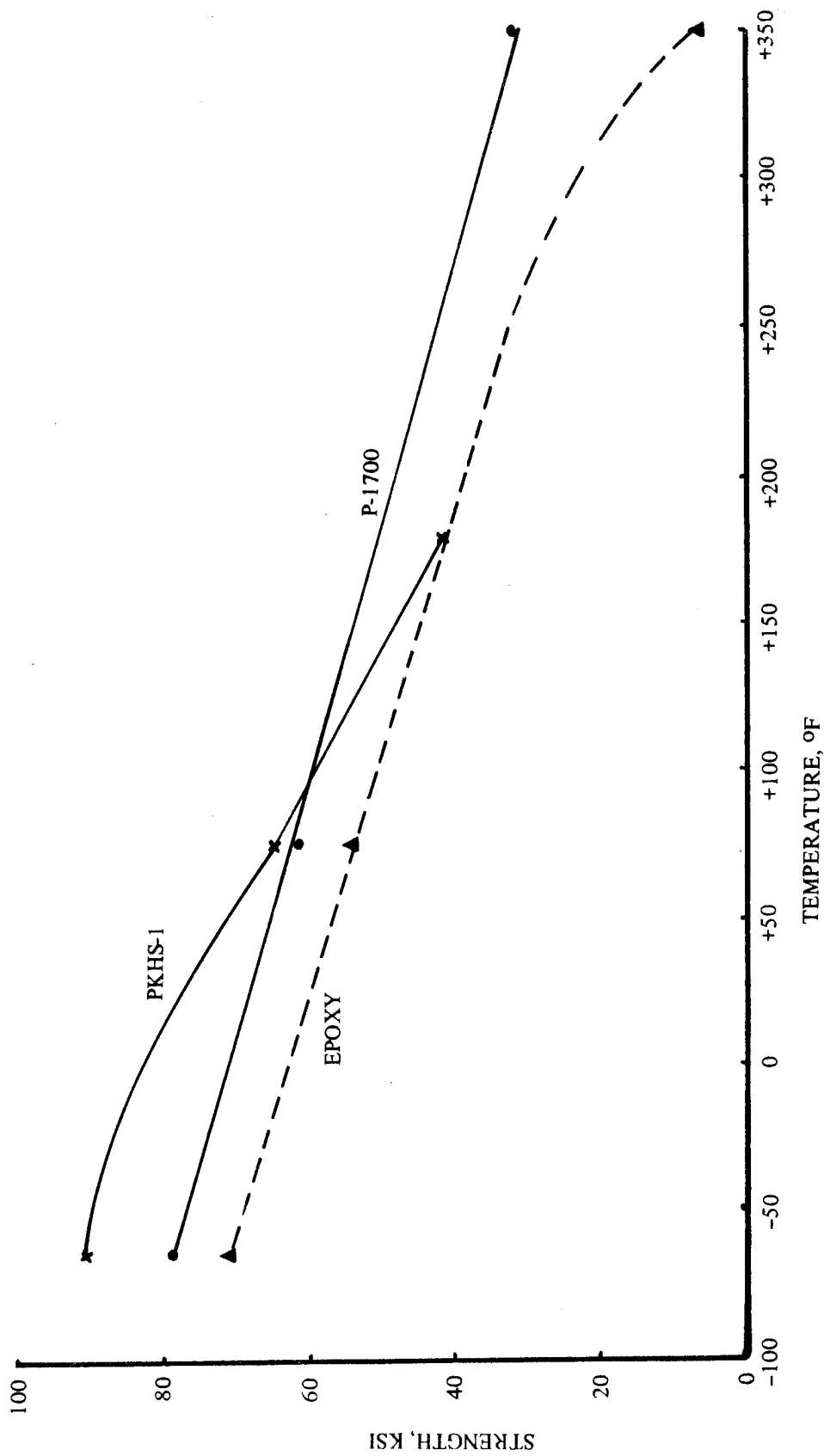
FIGURE 11   COMPRESSION STRENGTH VS. TEMPERATURE OF·181 GLASS FABRIC LAMINATES
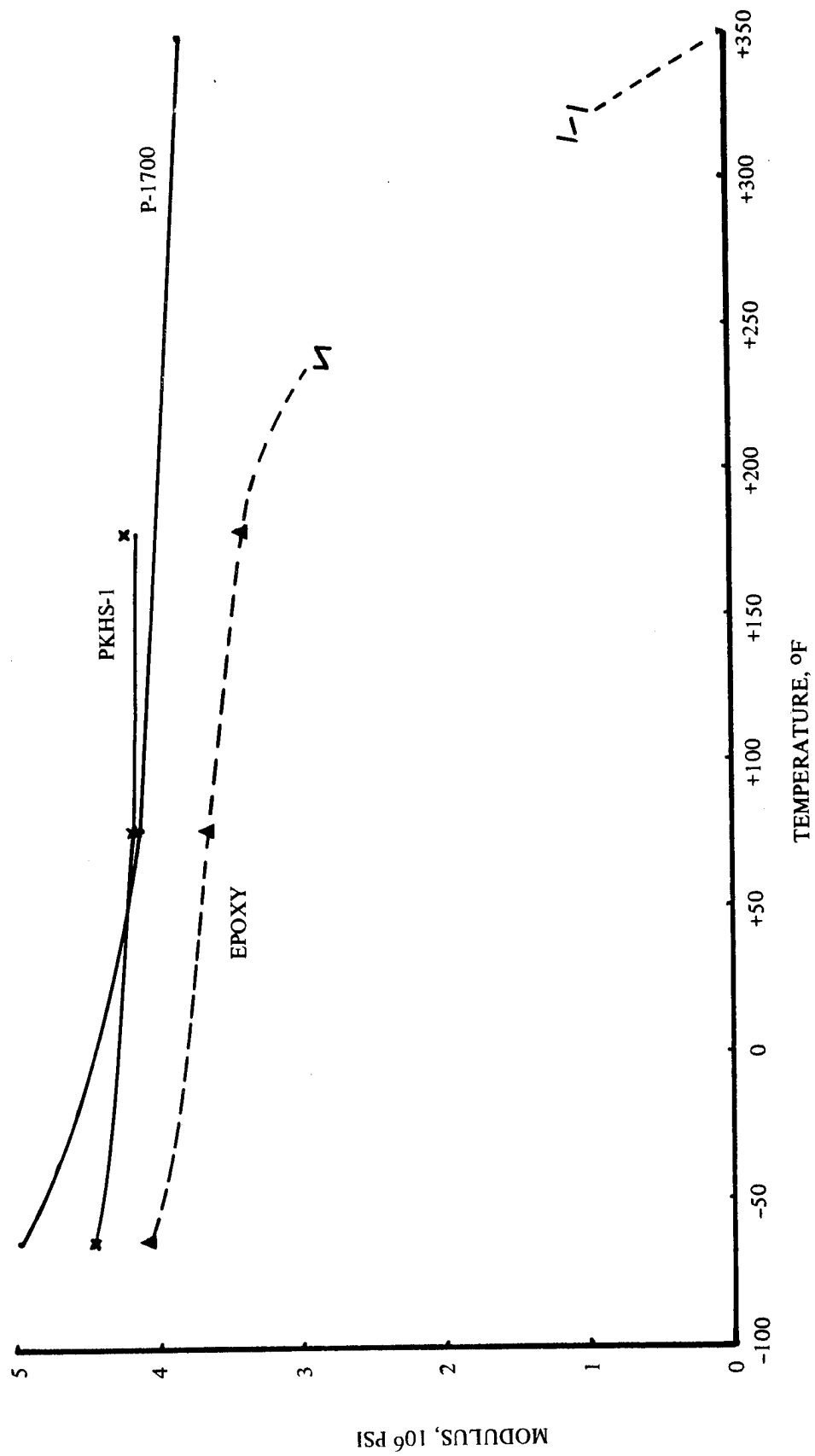
FIGURE 12   COMPRESSION MODULUS VS. TEMPERATURE OF 181 GLASS FABRIC LAMINATES

EPOXY

P-1700

PKHS-1
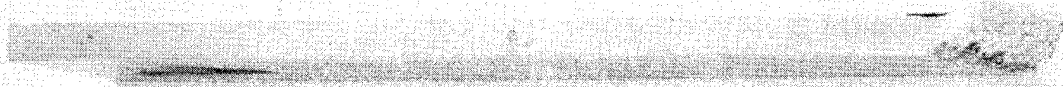
FIGURE 13 TYPICAL FAILURES — COMPRESSION SPECIMENS
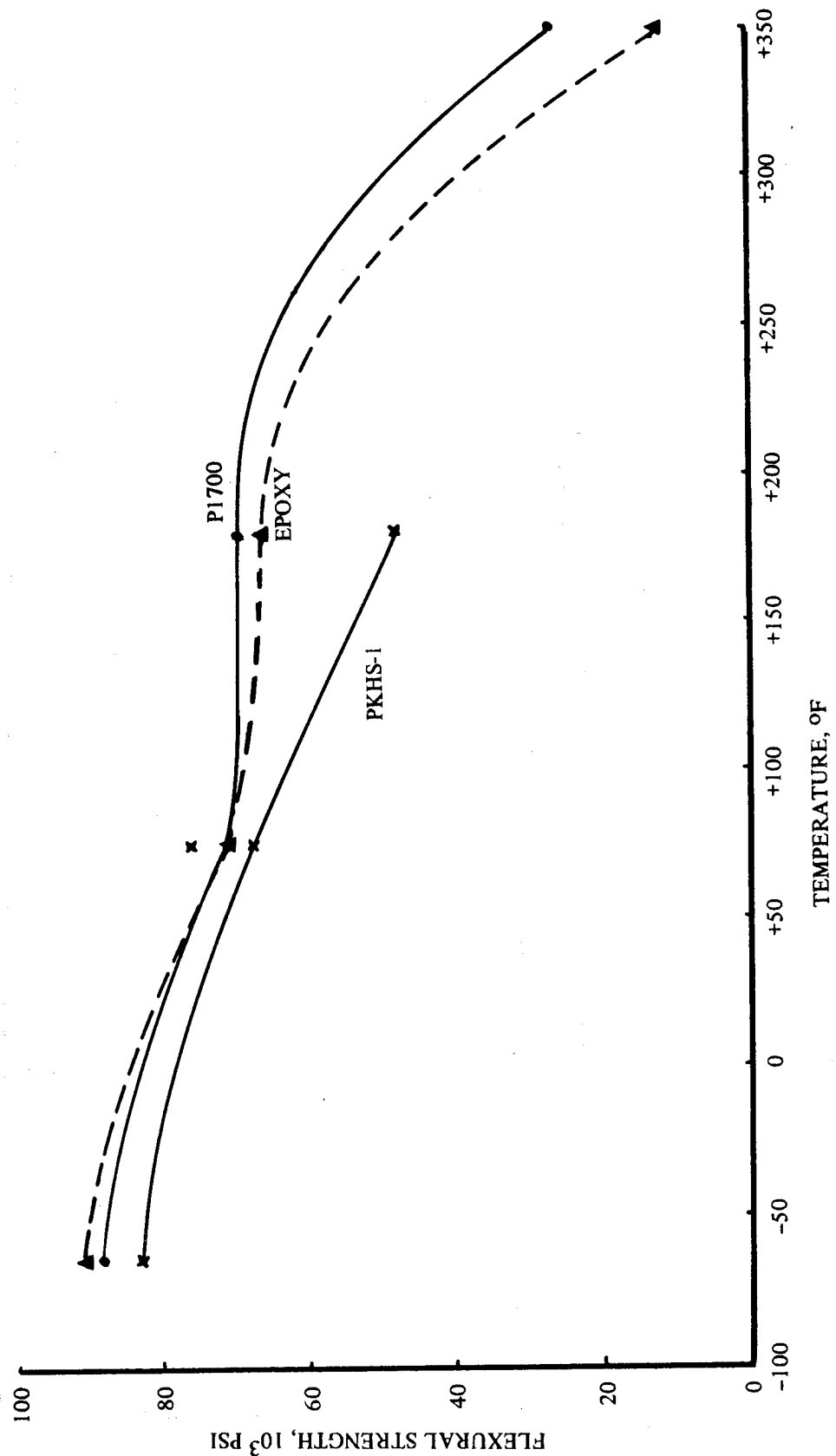
FIGURE 14   FLEXURAL STRENGTH VS. TEMPERATURE OF 181 GLASS FABRIC LAMINATES

25
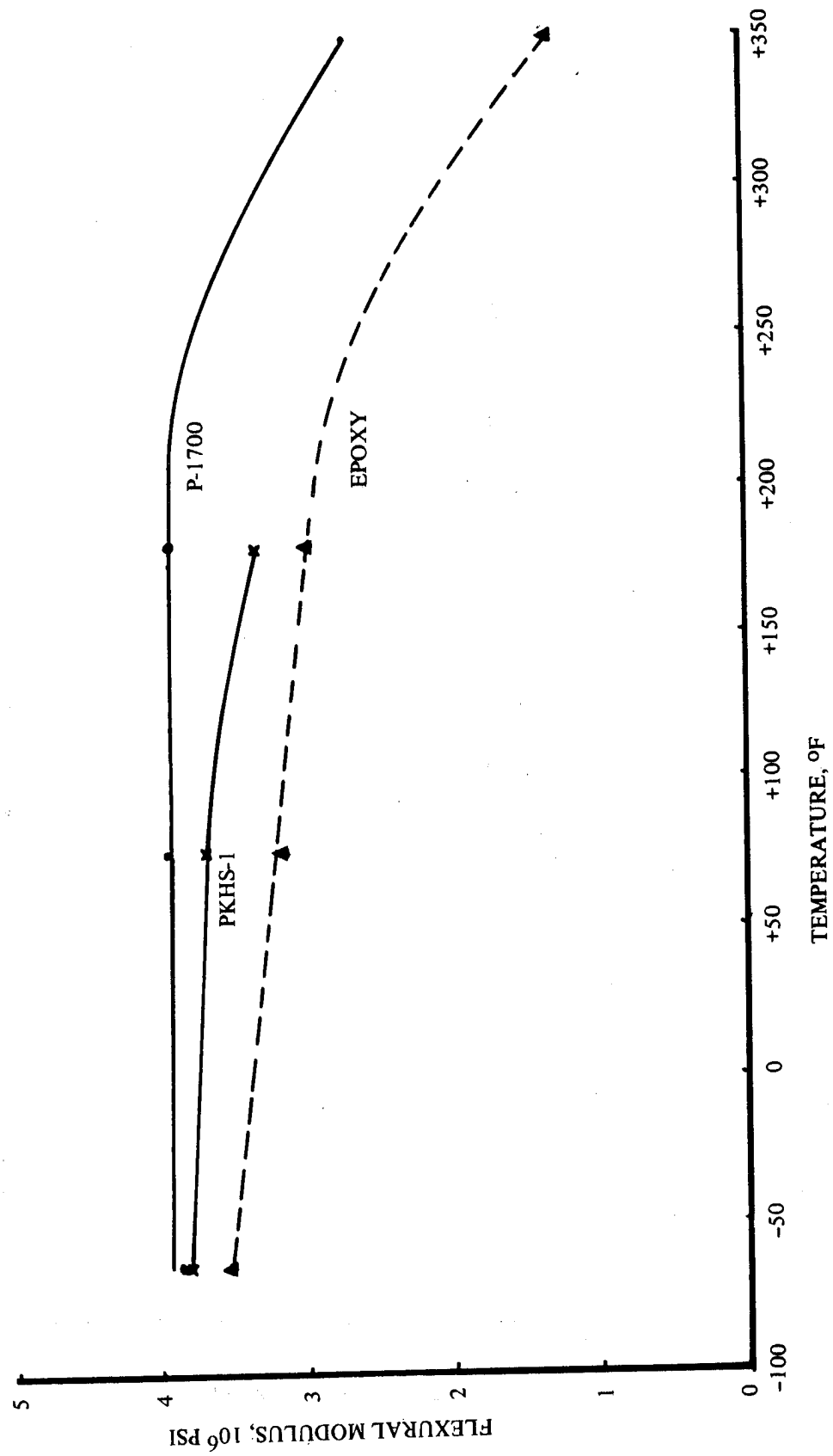
FIGURE 15 FLEXURAL MODULUS VS. TEMPERATURE OF 181 GLASS FABRIC LAMINATES

26

2.1.3.3   (Continued)

The results of the flexural tests indicates that +180°F is about the maximum service temperature for the PKHS-1 component laminate. The specimens showed the initiation of plastic deformation and failure at that temperature. Similar observations were made on the P-1700 specimens at +350°F, when tested in flexure. These types of failures were not noted in the tension or compression tests at equivalent temperatures.

A scanning electronic photomicrograph of the fractured surface of the thermoplastic laminates (+70°F) are shown in Figures 16 and 17.

2.1.3.4   Interlaminar Shear Properties

Short beam interlaminar shear tests were conducted per ASTM Test Method D2344 at a span-to-depth ratio of 4:1 over a temperature range of -65°F to +350°F.

The interlaminar shear strength of all three laminates varied linearly with temperature, although at different slopes as shown in Figure 18. Both the thermoplastic laminates exhibited lower interlaminar shear strengths than the epoxy control. The P-1700 was the lowest; about 25% below that of the epoxy laminate. Even though the values were low, they appear acceptable for most structural applications.

2.1.3.5   Notched-Izod Impact Strength

Notched-Izod impact tests were conducted per ASTM Test Method 256-56T and these results are shown in Figure 19. As is evident from the data, the thermoplastic laminates exhibit a 30-40% increase in impact strength over the epoxy control laminates. The control laminate value of 10.9 ft-lb/inch compares favorably with other results reported on epoxy/glass laminate (Ref. 5). The thermoplastic resins in the pure cast form exhibit good impact strength and this characteristic appears to translate well to the composite.

2.1.3.6   Creep Evaluation

Tensile creep tests were performed on a series of 181 glass fabric laminates at +72°F, +350°F. The specimens were loaded at 50% of ultimate strength and the results of these tests are shown in Figure 20.
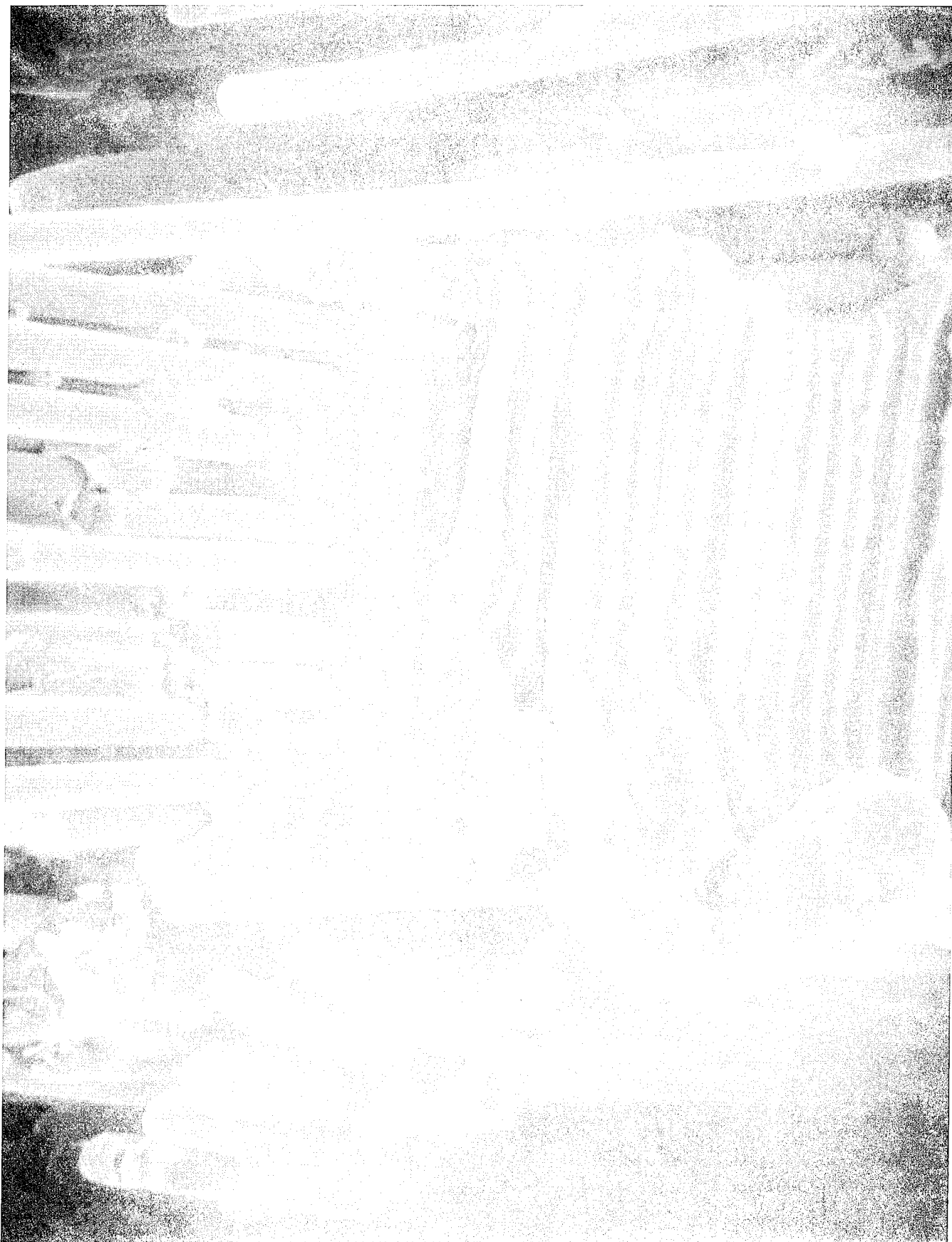
FIGURE 16 SCANNING ELECTRON PHOTOMICROGRAPH
OF A PKHS-1/181 GLASS FABRIC LAMINATE (500X)

28
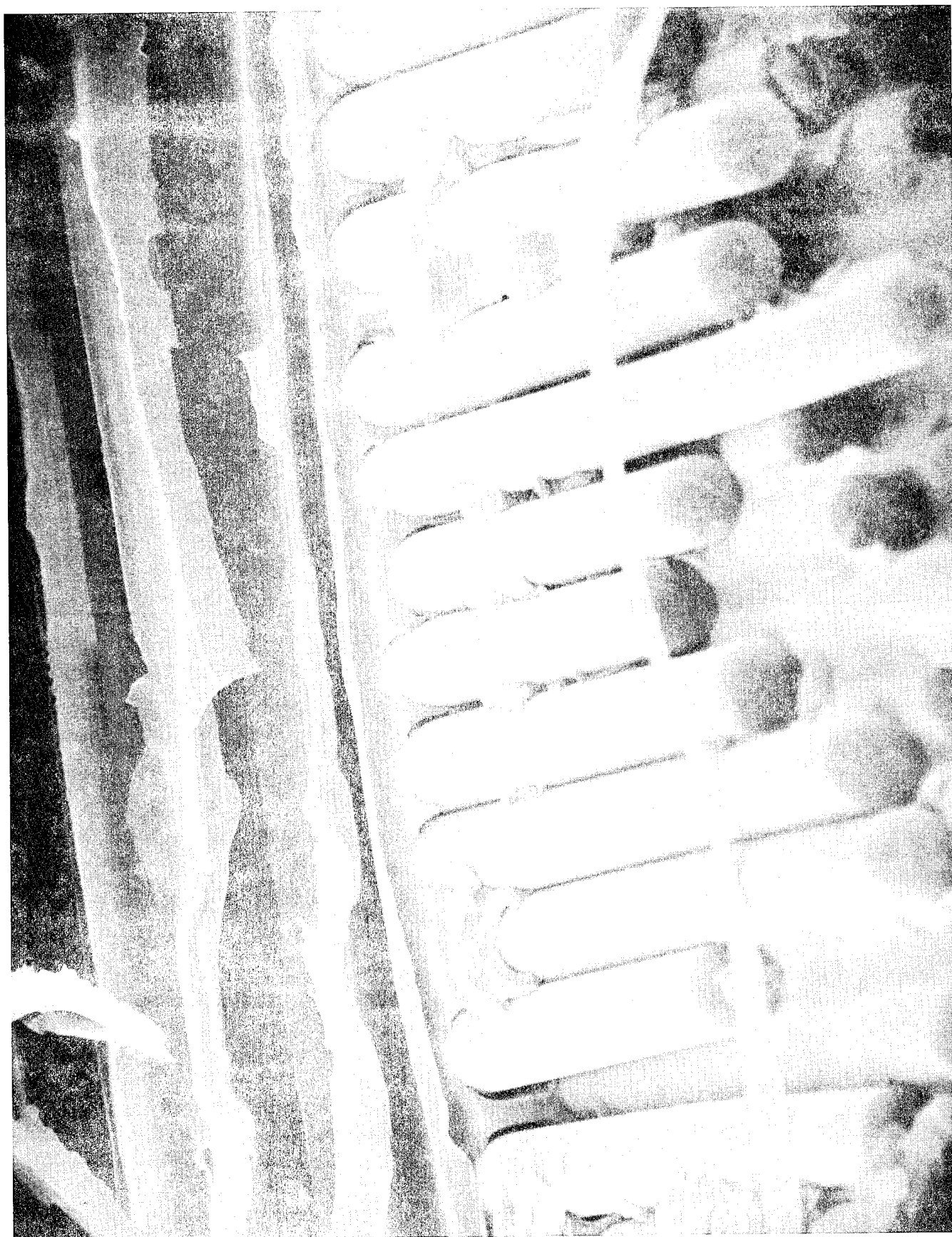
FIGURE 17   SCANNING ELECTRON PHOTOMICROGRAPH OF A P–1700/181
GLASS FABRIC LAMINATE (1000X)

29

SDR = 4

EPOXY

PKHS-1

P-1700

STRENGTH, KSI

16
14
12
10
8
6
4
2
0

-100   -50   0   +50   +100   +150   +200   +250   +300   +350
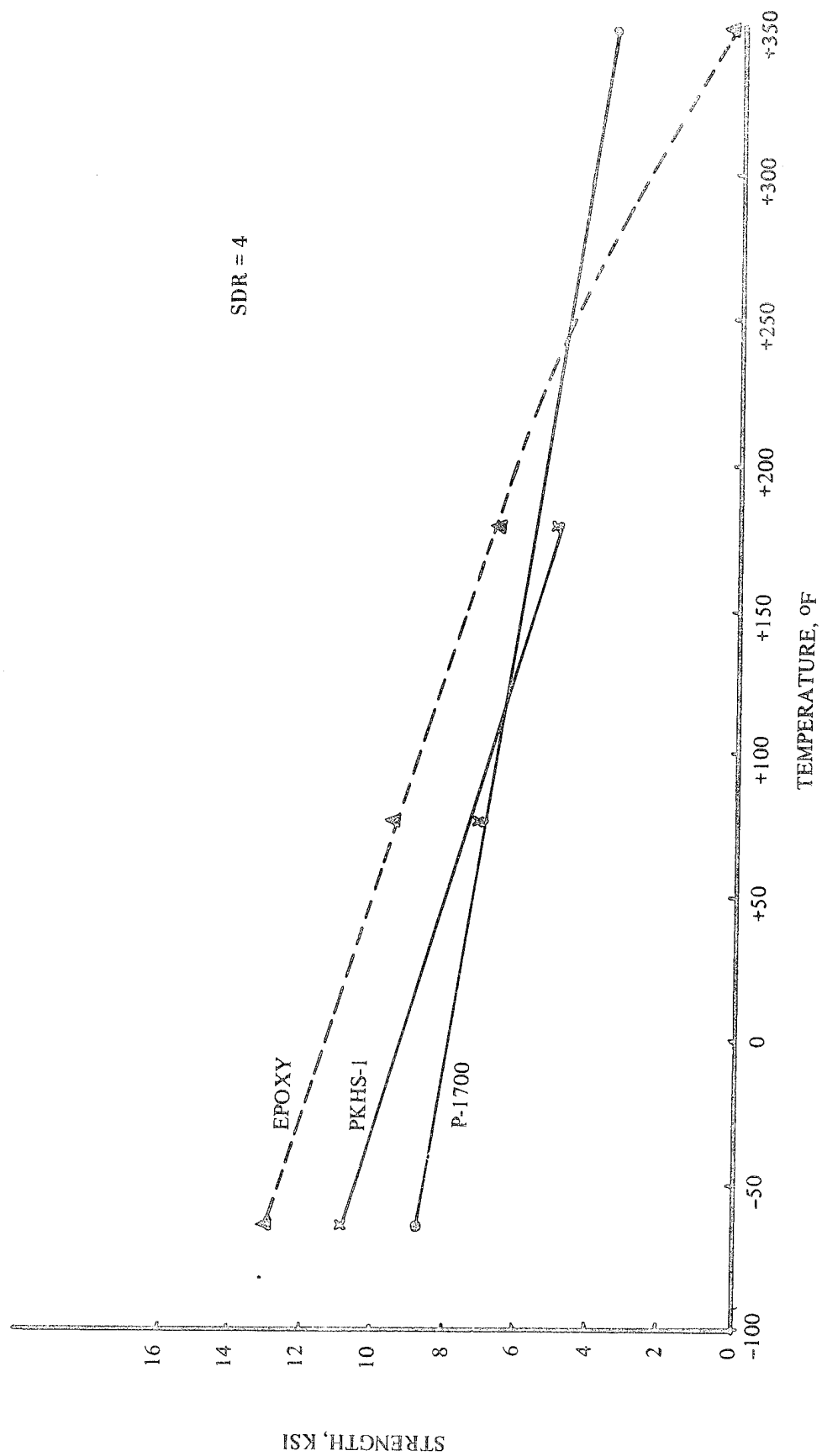
TEMPERATURE, °F

FIGURE 18   INTERLAMINAR SHEAR STRENGTH VS. TEMPERATURE OF 181 GLASS FABRIC LAMINATES

30
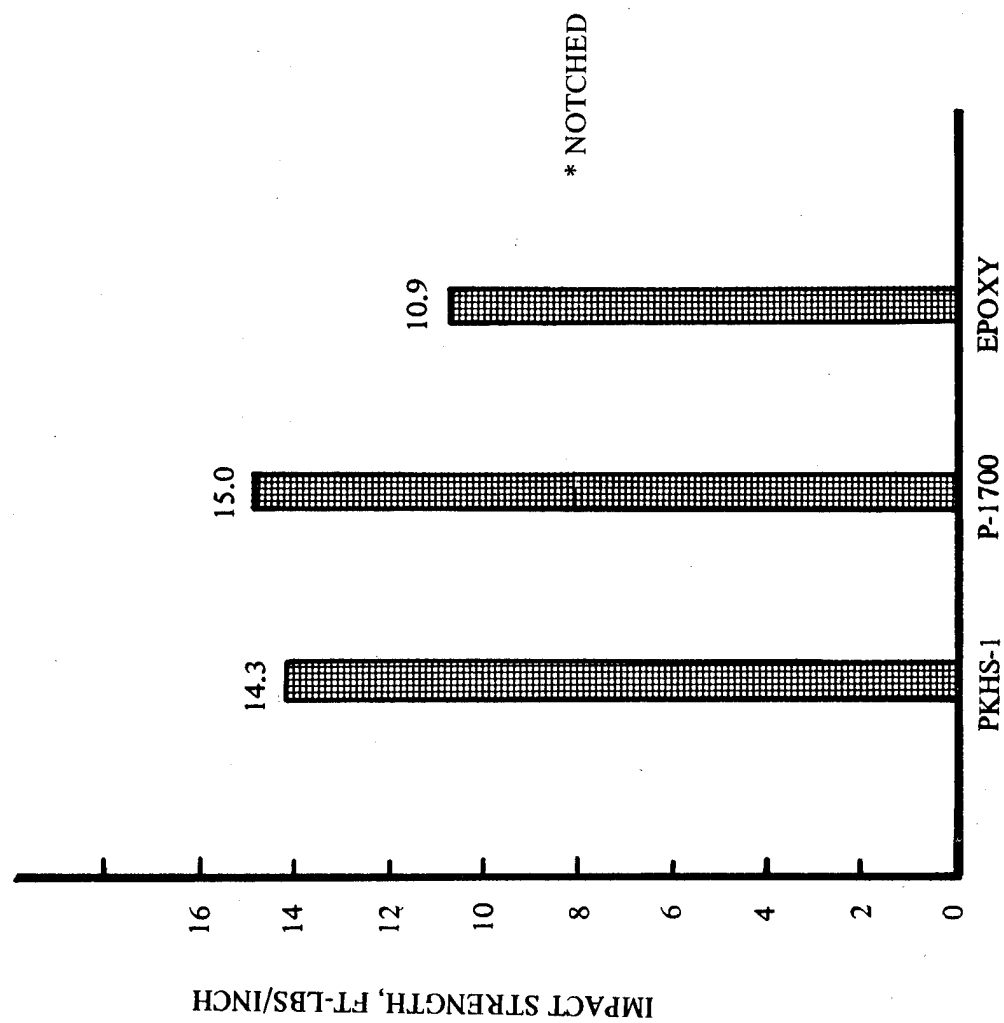
FIGURE 19   IZOD IMPACT STRENGTH* OF 181 GLASS FABRIC LAMINATES
(ASTM 256-56T)
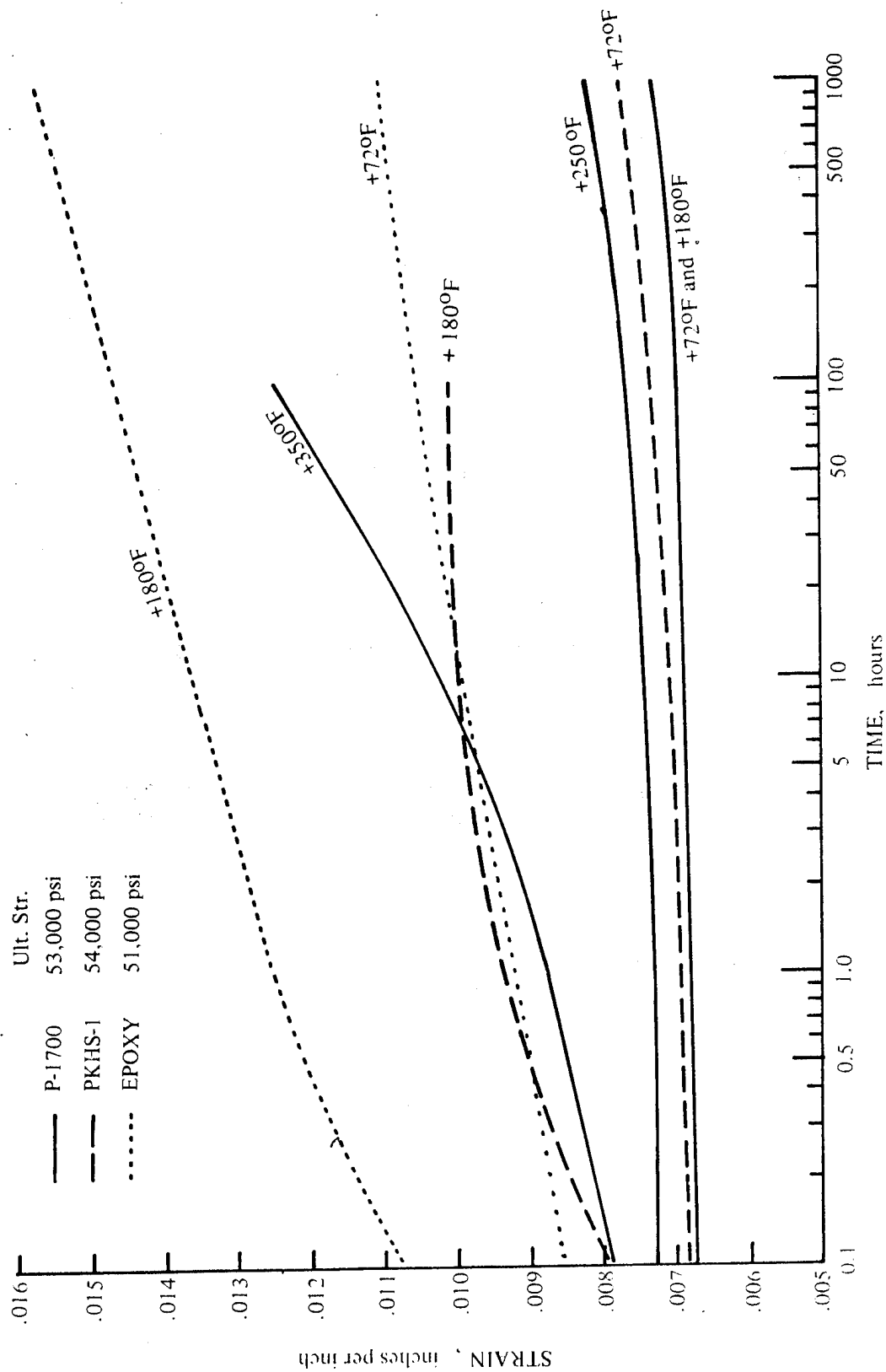
FIGURE 20 TENSILE CREEP DATA FOR 181 GLASS FABRIC LAMINATES (50% of ULT.)

2.1.3.6   (Continued)

At +72° F, and +180° F the P1700 laminates exhibited very low creep (< .0005 in/in in 1000 hours) and the amount of creep did not change within that temperature range. The low creep properties of P1700 polymer was one of the prime selection criteria used initially.   Based on supplied data (Ref 4) and previous Boeing creep tests at +250° F (Ref. 1) the polysulfone laminates should exhibit little change in creep behavior up to +300° F. The +250° F results previously obtained on polysulfone laminates are shown in Figure 20 .   The phenoxy laminate demonstrated about the same degree of creep at +72° F. At +180° F, which is near the HDT for the phenoxy, the material exhibited moderate creep behavior and then failed after about 100 hours. The polysulfone laminates exhibited similar behavior when tested at +350° F, which is slightly above its HDT (+345° F). As shown in Figure 20 , at 350° F the polysulfone showed definite signs of creep.

The epoxy control laminate had a greater initial elongation that either the phenoxy or the polysulfone laminates as shown in Figure 20 and Figure   9 , section 2.1.3.1. The creep characteristics of the epoxy was also greater than either of the thermoplastic laminates at +72° F and could not match the performance of the P-1700 at +180° F.

In conclusion, the P1700 and PKHS-1 laminates do not appear to pose a serious creep problem if used below their heat distortion temperatures. These results are consistent with previous creep studies performed on thermoplastic laminates (Ref. 1   ).

2.1.3.7   Fatigue Studies

Figure 21   shows a comparative S-N curve for PKHS-1, P1700 and epoxy -181 glass fabric laminates at +70° F. The thermoplastic and the epoxy control laminates appear to have similar data trends at the stress levels tested and no serious deficiencies were noted. The fatigue life of the epoxy may be slightly better at the lower stress levels (∿ 40% of ult. stress) but this is not certain. The epoxy laminate evaluated had a resin content of 38% by weight which was slightly higher than any of the other materials.

33
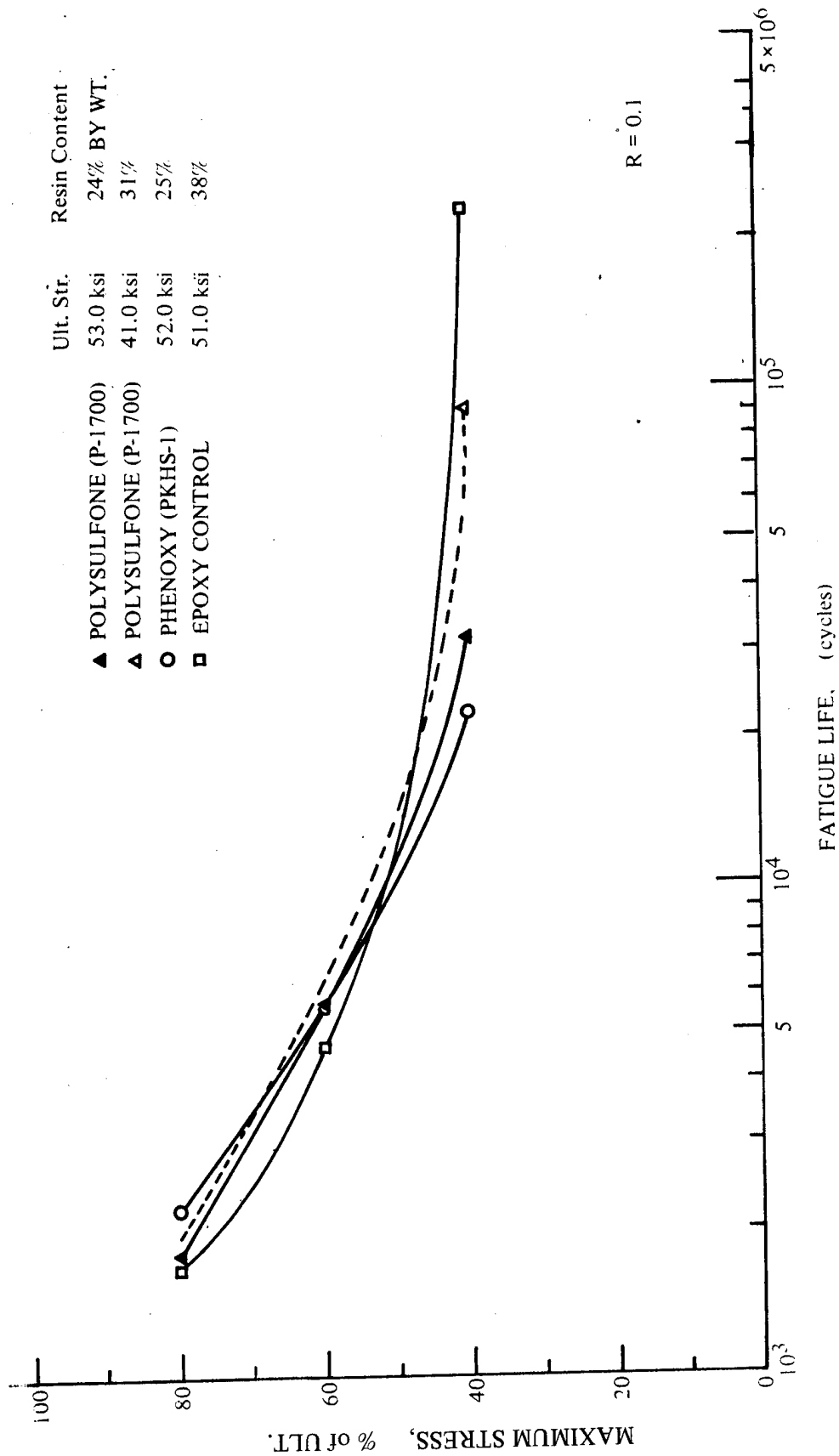
FIGURE 21 FATIGUE LIFE OF 181 GLASS FABRIC LAMINATES (+70°F)

34

2.1.3.7 (Continued)

The polysulfone showed a slight improvement in fatigue strength when the resin content of the laminate was increased from 25% to 31% by weight. Increasing the resin content to 38% may extend the fatigue life at the lower stress levels but this is merely speculation. The existing differences between the polysulfone and the epoxies is relatively small and considering the small data sample, the comparison of the materials appears favorable.

2.1.4 ENVIRONMENTAL STUDIES

The thermoplastic glass fabric laminates were subjected to a series of tests to assess their stability and resistance to various service environments. The tests included thermal stability, flammability, accelerated weathering, salt-water exposure, water-boil and resistance to various service fluids. Unless otherwise stated, the 181 glass fabric laminates were exposed as test specimens, in contrast to full sheets, to have maximum edge exposure and then tested in flexure at +70°F.

2.1.4.1 Thermal Stability

To evaluate the isothermal aging characteristics of the thermoplastic glass fabric laminates, phenoxy (PKHS) samples were exposed to +180°F and the polysulfone (P-1700) specimens were exposed to +350°F for periods up to 1000 hours. Epoxy control samples were exposed at both temperatures. Periodically, samples of each material were removed, examined, weighed and then tested. The results of the exposure on the flexural strength and modulus is shown in Figure 22, while the physical property changes are noted in Table A-1. Also shown in Table A-1, are the individual test results.

The isothermal aging had no effect on strength, modulus, appearance, weight, dimension, or other physical characteristics of the thermoplastic laminates. The epoxy controls, on the other hand, experienced both strength and modulus degradation, change in color and approximately a 3.5% weight loss at +350°F. The change in the epoxy controls was not unexpected since the system is not suited for such high temperature exposure.

35
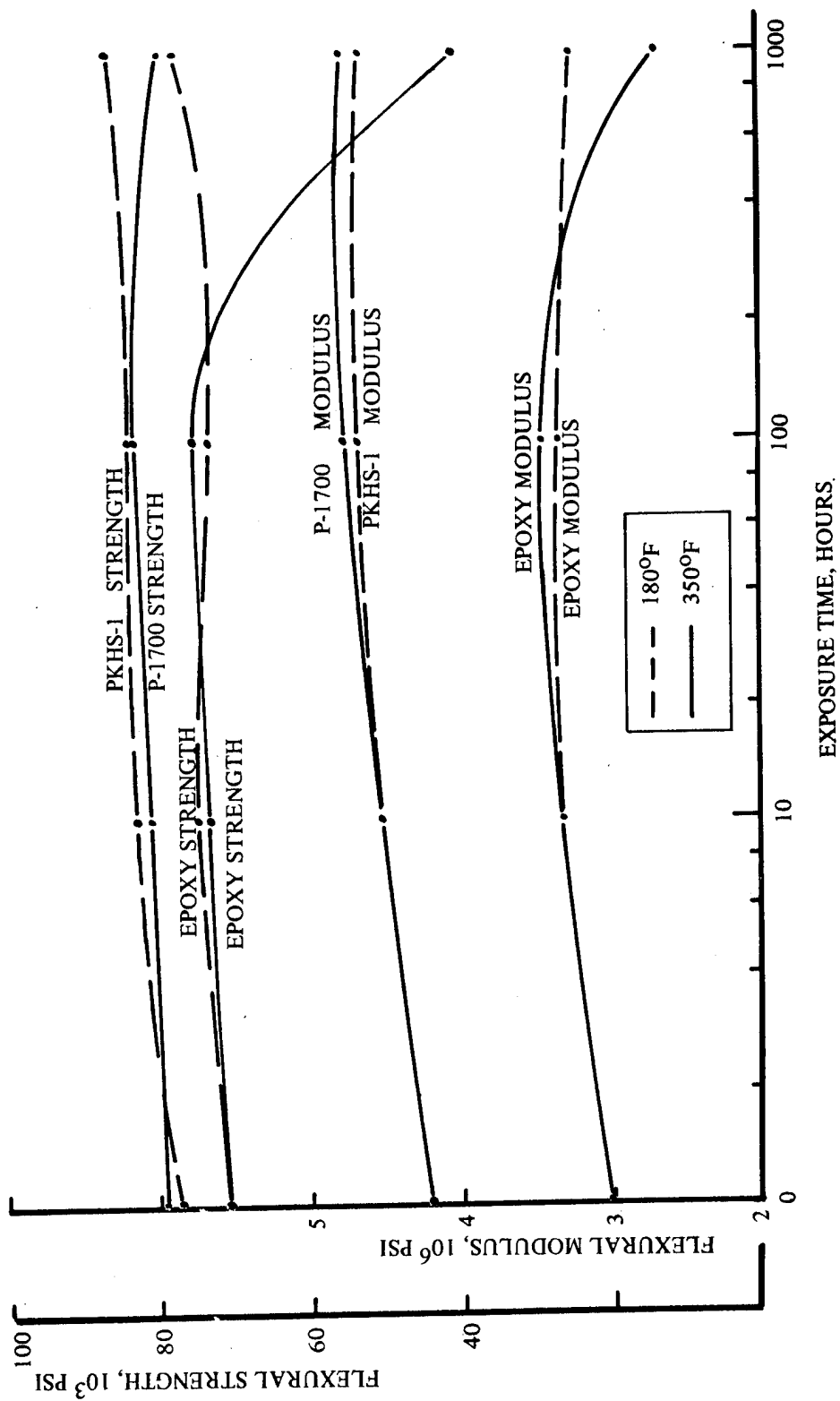
FIGURE 22   EFFECTS OF ISOTHERMAL EXPOSURE OF 181 GLASS FABRIC LAMINATES
(TESTED AT +70°F)

36

2.1.4.1   (Continued)

The P-1700 is a very thermally stable polymer as shown in Figure 22 and exhibits only minor weight loss at +350°F. In contrast, the high temperature epoxy systems, in general, experience a 1-1.5% weight loss after 1,000 hours at +350°F. (Ref. 7)

2.1.4.2   Flammability

Each material was assessed for flammability per ASTM D635-63 and the results are given in Table 5. The P-1700 and the epoxy control were non-burning materials, while the phenoxy was classified as self-extinguishing. Figure 23 shown a typical burnt specimen of each material.

2.1.4.3   Weathering

Weathering characteristics of the materials were evaluated by subjecting specimens to 200 hours of alternating rain and sunlight cycles. Tests were conducted in a weatherometer per ASTM D1499-64. Each 20 minute cycle consisted of a rain and sunlight cycle of equal duration. The temperature of the chamber was maintained at 145°F on the sunlight cycle and 108°F on the rain cycle.

The accelerated weathering tests had no effect on any of the three laminates as shown in Figure 24. In fact, each of the materials exhibited a minor increase in both strength and modulus as a result of the exposure. The individual test specimen data and physical property measurements are tabulated in Table A-2. The conclusions from these tests were that the thermoplastic laminates were as resistant to weathering as the epoxy control.

2.1.4.4.   Salt-Water Exposure

Flexure specimens were placed in a salt spray chamber for 200 hours to study their salt water resistance. The chamber (per ASTM B117-64) had an environment of 100% R.H., 100°F with a 5% Na Cl solution. At the end of the exposure period, the specimens were removed, weighed and examined and placed in a sealed container to prevent the loss of moisture until testing. The results of the flexural tests are shown in Figure 25 and tabulated in Table A-3.

No deterioration or property degradation was noted in any of the laminates. The materials were stable dimensionally and experienced no weight increase (no moisture pick-up — Table A-4).

37

MATERIAL	SPECIMEN NO.	SPECIMEN THK. (IN.)	BURNING RATE
		TABLE 5	FLAMMABILITY TEST
			(ASTM D635-63)
P-1700	34-2-1	.076	NON-BURNING
	34-2-2	.076	NON-BURNING
	34-2-3	.076	NON-BURNING
	34-2-4	.077	NON-BURNING
	34-2-5	.077	NON-BURNING
PKHS-1	28-4-1	.082	SELF-EXTINGUISHING (.30 INCH/MIN)
	28-4-2	.083	SELF-EXTINGUISHING (.37 INCH/MIN)
	28-4-3	.082	SELF-EXTINGUISHING (.44 INCH/MIN)
	32-5-4	.078	SELF-EXTINGUISHING (.38 INCH/MIN)
	32-5-5	.079	SELF-EXTINGUISHING (.40 INCH/MIN)
EPOXY (CONTROL)	1-1	.100	NON-BURNING
	1-2	.100	NON-BURNING
	1-3	.099	NON-BURNING
	1-4	.100	NON-BURNING
	1-5	.099	NON-BURNING

EPOXY

P-1700

PKHS-1
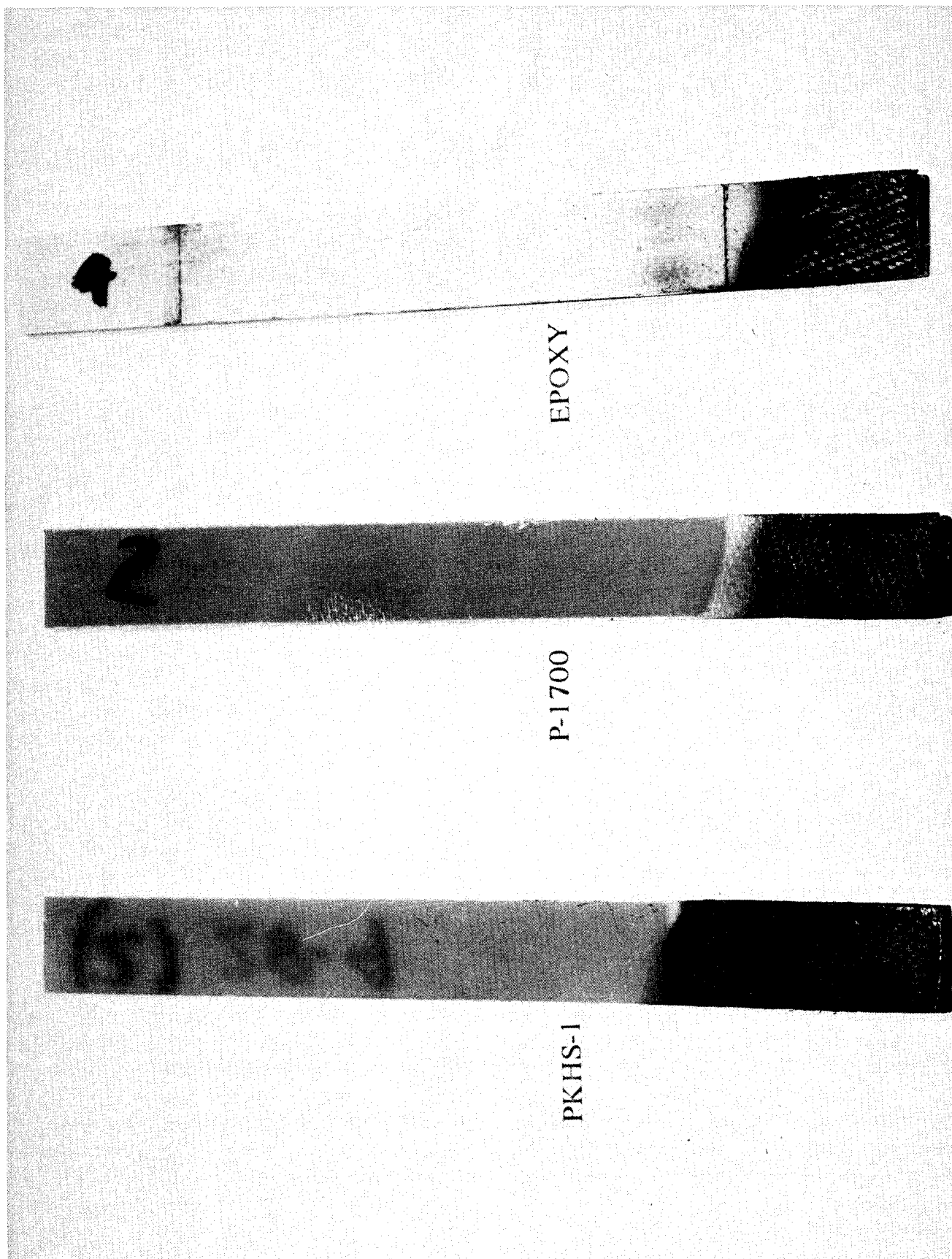
FIGURE 23   TYPICAL RESULTS OF FLAMMABILITY TESTS
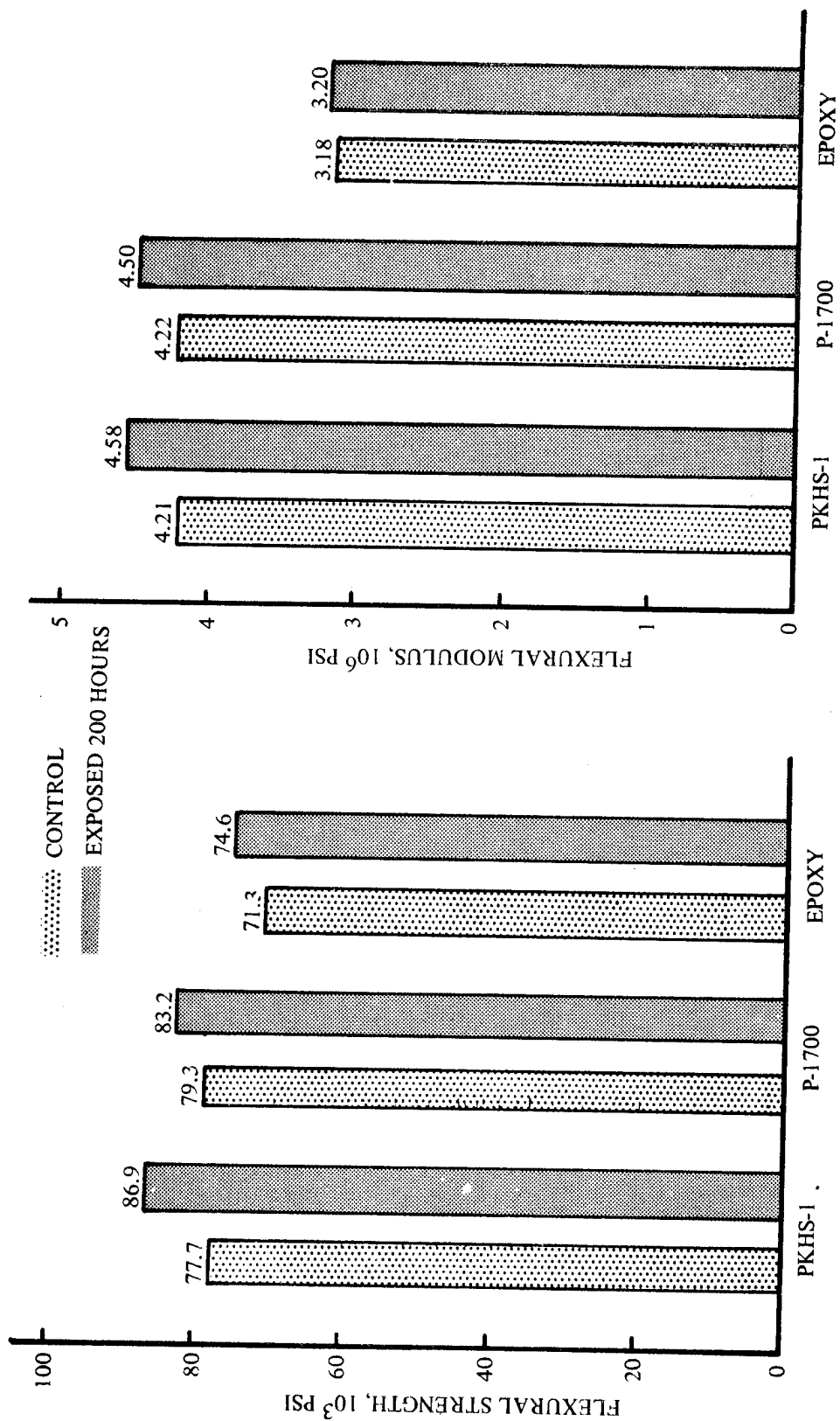
FIGURE 24   EFFECTS OF ACCELERATED WEATHERING OF 181 GLASS FABRIC LAMINATES
(ASTM D1499–64)

40

FIGURE 25   EFFECTS OF SALT WATER EXPOSURE OF 181 GLASS
FABRIC LAMINATES (ASTM B117–64)
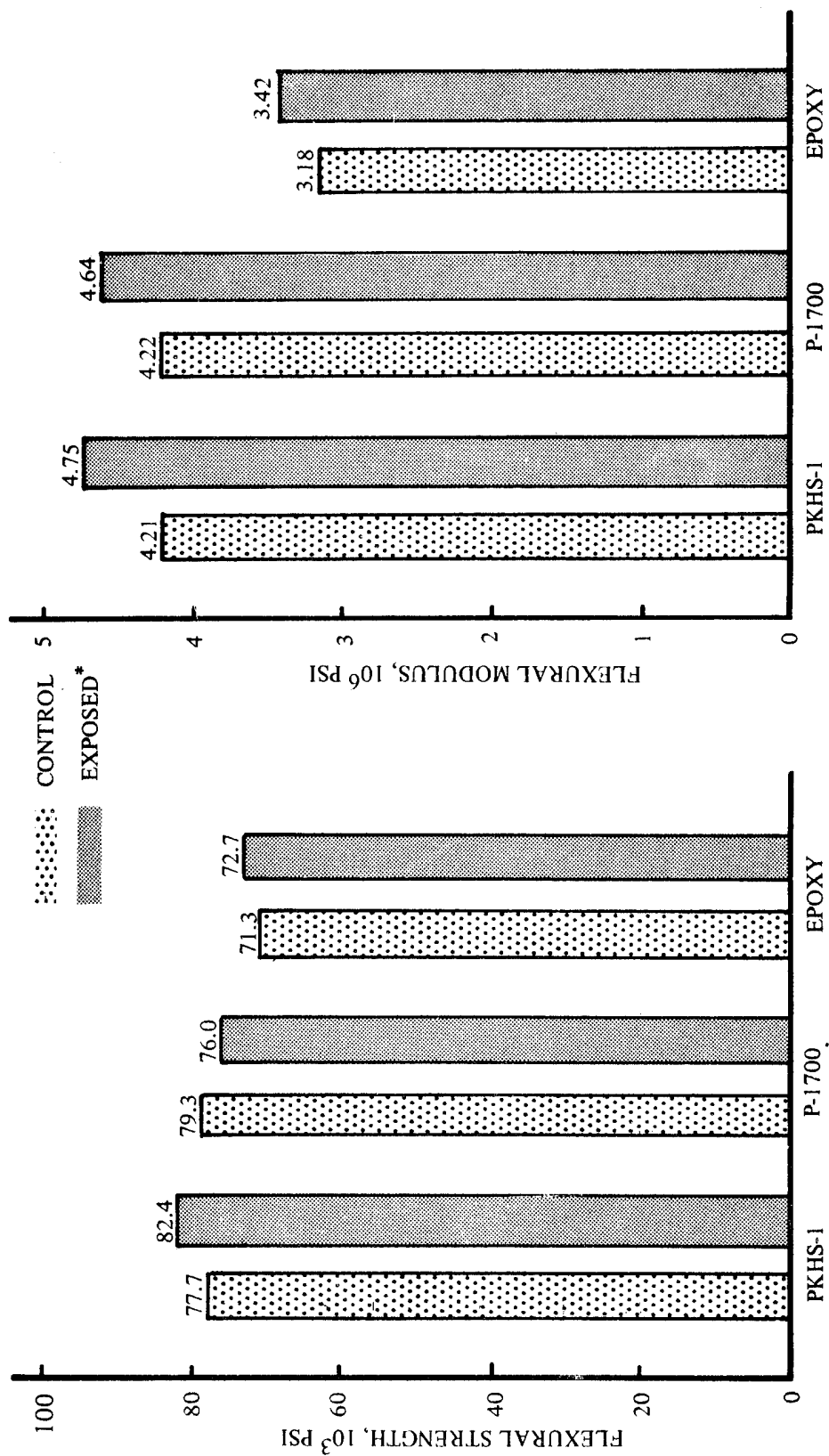
* SAMPLES EXPOSED 200 HOURS IN SALT SPRAY CHAMBER

41

2.1.4.5 Water-Boil

Laminate samples were exposed to a 72-hour water-boil and then tested. All the materials suffered some property degradation as a result of that exposure as shown in Figure 26 and Table A-5. The polysulfone laminate experienced a 41% reduction in flexural strength which was the most severe of the three materials. The phenoxy and the epoxy control laminates lost 28% and 23% in flexural strength, respectively. The effect of exposure on flexural modulus did not establish a common trend. The phenoxy laminates experience approximately a 36% increase in modulus, while the polysulfone laminates showed a 13% decrease and the modulus of the epoxy control remained essentially constant. An interesting observation is that the polysulfone laminates, which appear to suffer the most deterioration in the water-boil, had the lowest percentage (.21%) of moisture pick-up (Table A-5). The phenoxy laminates, on the other hand, had a 9.8% weight increase due to the water-boil exposure, yet the degradation of the laminate properties was not significantly different from the epoxy control laminate. The epoxy laminate gained 2.94% in weight. The phenoxy was the only material to show any noticeable change in appearance. It changed from a translucent green to an opaque white. These observations and the moisture pick-up seem to indicate that the water boil effected the polymer in the case of the phenoxy laminates while the degradation in the polysulfone and epoxy laminates resulted from an attack at the polymer-glass interface. The polysulfone polymer did not appear changed.

2.1.4.6 Fluid Resistance

One of the big concerns with thermoplastic matrix materials is their resistance to aircraft fuels and maintenance fluids. To assess this problem, samples of the phenoxy and polysulfone glass fabric laminates were exposed to JP-4 jet fuel, hydraulic fluid (MIL-H-5606), and aircraft lubricant (MIL-L-7808). Exposure times were 7 days at 70°F, 28 days at 70°F, 1 day at 160°F and 7 days at 160°F.

The results of the polysulfone, phenoxy and epoxy laminate exposures are presented in Figures 27, 28, and 29, respectively. None of the materials degraded as a result of the exposure. For these particular fluids, which are the most frequently handled around military aircraft, the thermoplastic materials appear to be as resistant and stable as the epoxy systems. This is not to imply that the polymers are resistant to

42
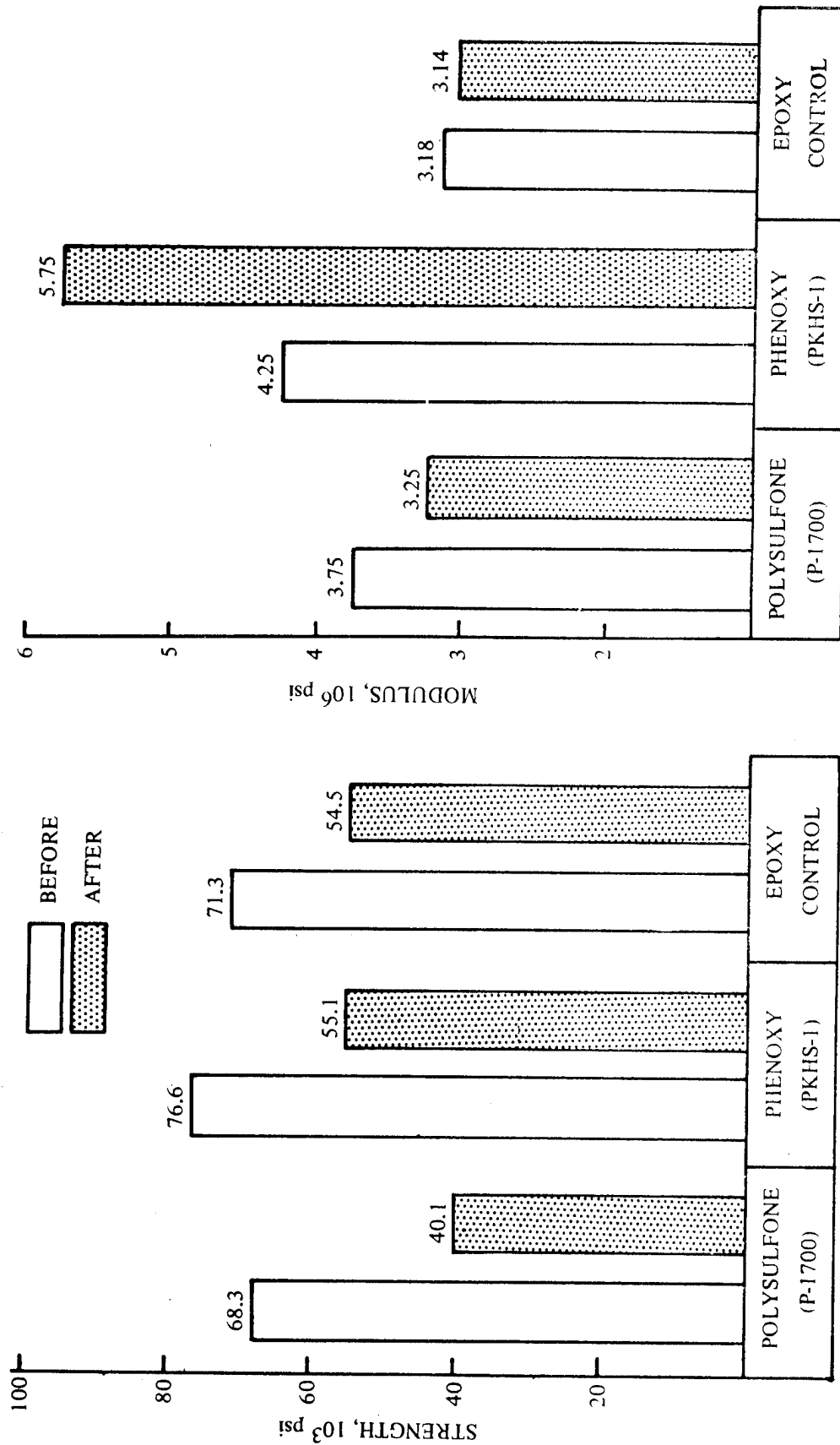
FIGURE 26 EFFECT OF EXPOSURE TO 72-HOUR WATER BOIL ON FLEXURAL PROPERTIES OF 181 GLASS FABRIC LAMINATES
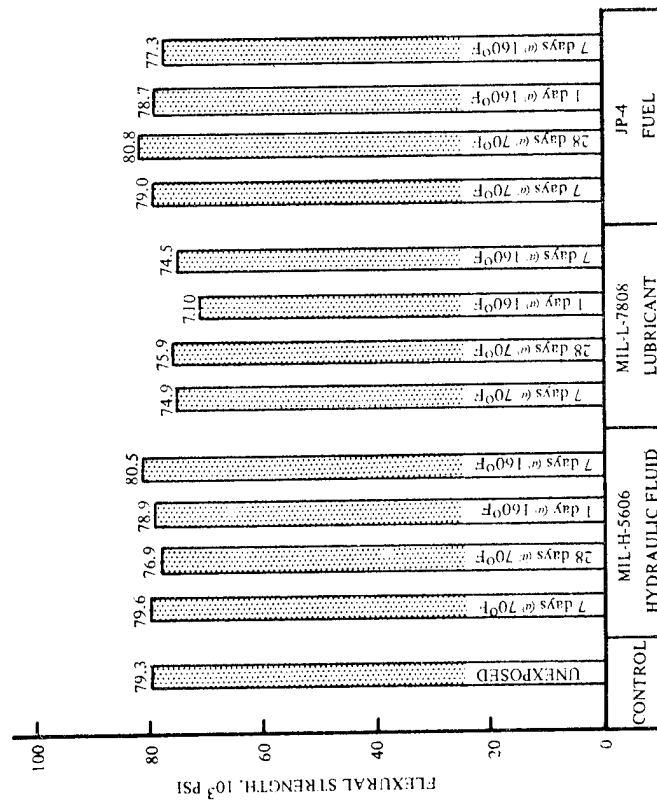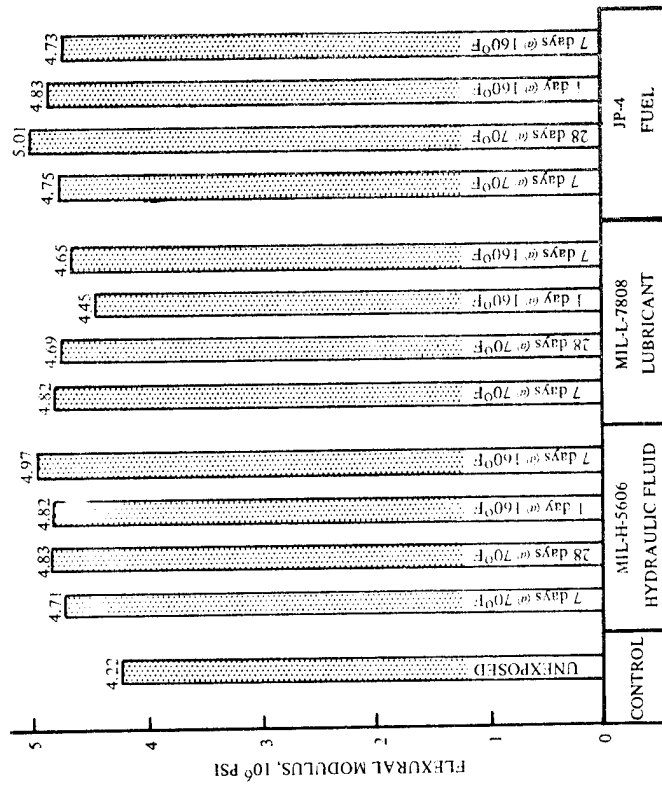
FIGURE 27   FLUID RESISTANCE OF P–1700/181 GLASS FABRIC LAMINATE   (TESTED AT +70°F)

44
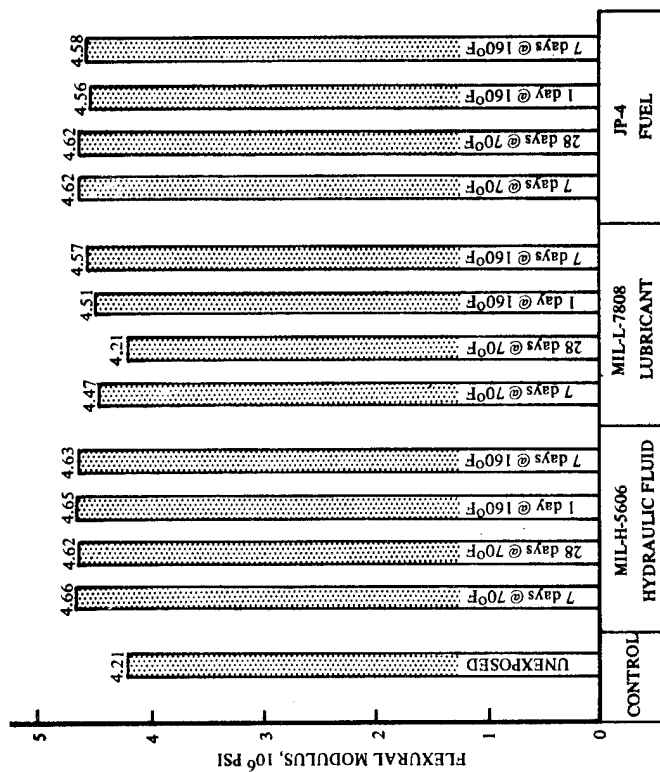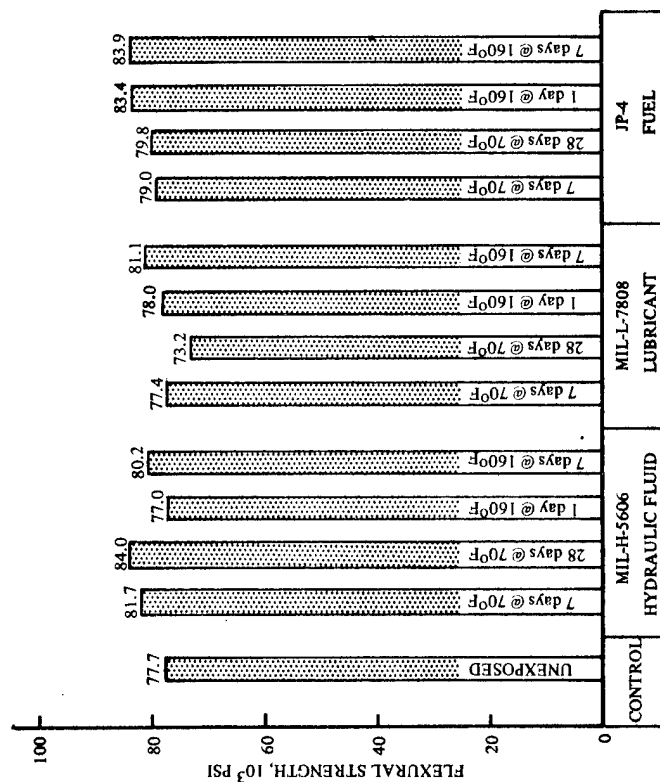
FIGURE 28   FLUID RESISTANCE OF PKHS-1 / 181 GLASS FABRIC LAMINATE (TESTED AT +70°F)

45
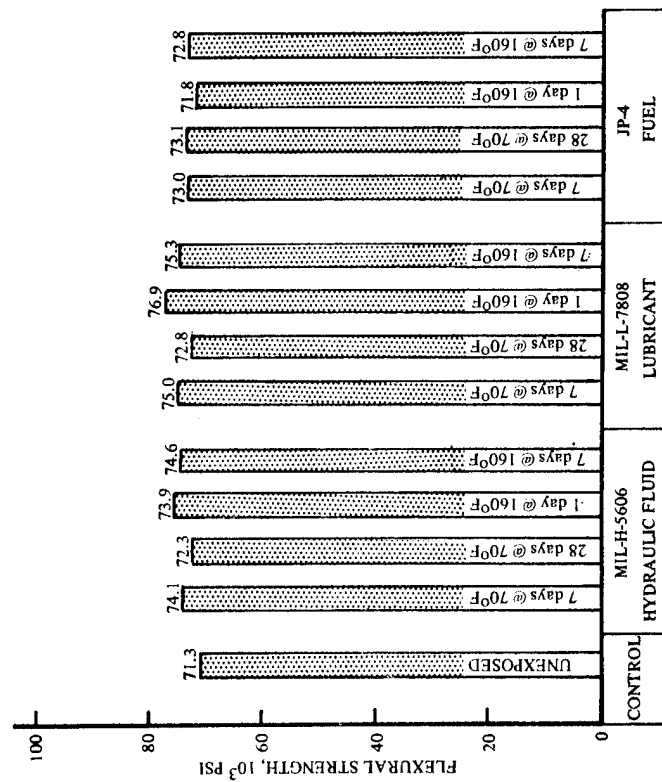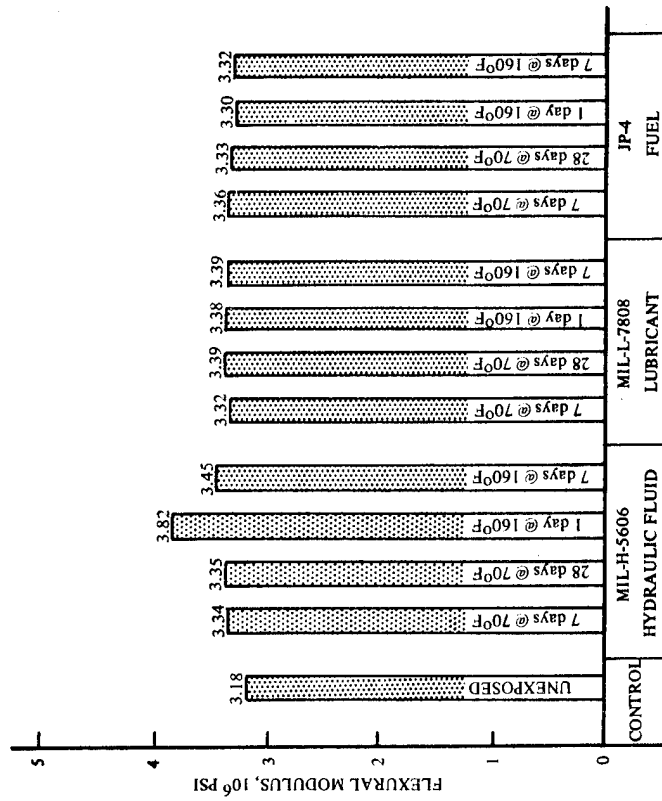
FIGURE 29   FLUID RESISTANCE OF EPOXY / 181 GLASS FABRIC LAMINATE   (TESTED AT +70°F)

46

2.1.4.6 (Continued)

All aircraft solvents. In fact, as a prevention, thermoplastic composites should possibly be coated with an epoxy paint or other protective finish to prevent solvent damage. The polysulfone polymer, for instance, is highly resistant to mineral acids, alkali, salt solutions, detergents and hydrocarbon oils but will be attacked by polar organic solvents, such as ketones, chlorinated hydrocarbons, and aromatic hydrocarbons (Ref. 4). The phenoxy polymer, in general, is attacked by a greater variety of solvents. It has demonstrated resistance to mineral acids, alkalis, aliphatic hydrocarbons, water and minteral salt solutions, but its resistance to most aromatic and polar solvents, and esters is generally poor (Ref. 3). The individual test dates are tabulated in Table A-6 through Table A-11. The effects on flexural strength and modulus is shown in Table A-6, A-8, and A-10 while the influence of fluids on the physical properties is summarized in Tables A-7, A-9 and A-11.

2.1.5   ELECTRIC PROPERTIES

The dielectric constant and loss tangent was determined on each laminate material. The laminates were 1/4" thick and were tested at +70°F at X-band frequency. The results of these tests are shown in Table 6. As the data shows, all three materials had dielectric constants of about 2.0 but the P1700 laminate had a loss tangent value 50% lower than either the epoxy or phenoxy materials. The loss tangent values of .013 and .014 obtained for the epoxy and PKHS materials, respectively, are typical of most epoxy laminates. The value of .007 obtained with the P1700 is excellent for most radome applications.

MATERIAL	RESIN CONTENT % BY WT.	SPECIFIC GRAVITY	DIELECTRIC CONSTANT	LOSS TANGENT
		TABLE 6 ELECTRICAL PROPERTIES* OF THERMOPLASTIC/GLASS FABRIC LAMINATES		
PKHS-1	26	2.03	5.07	.014
P-1700	24	2.05	5.01	.007
EPOXY (CONTROL)	38	1.86	4.58	.013

* TESTS CONDUCTED AT +70°F AT A FREQUENCY OF 9.375 GHz. (X-BAND).

2.2 PHASE II -- GRAPHITE FIBER REINFORCED THERMOPLASTIC COMPOSITE EVALUATION

Graphite fiber reinforced composites have demonstrated structural performance and weight advantages in many aircraft application. The majority of this work has been accomplished with epoxy or other thermosetting systems. Limited work has been performed with graphite reinforced thermoplastics with most of this being centered around molding compounds or chopped fiber composites. This phase of the program was directed toward taking the materials and processing information from Phase I and applying it to structural graphite reinforced composites. The principal objective was to determine fiber/resin compatibility and laminate quality. All the work in Phase II was performed with Type A graphite fiber and handled in unidirectional prepreg tape form. The composites were either unidirectional or 0°/90° laminates as noted. The resins used with the graphite were PKHS-1 phenoxy resin from Phase I and a polysulfone, designated 3004, from Hercules, Inc. The latter material was purchased as a 3 inch prepreg tape with type A-S continuous fiber.

2.2.1 PROCESSING STUDIES

The processing studies on the graphite composites were limited, and as initial processing conditions, the parameters used with the glass composites in Phase I were used. These were 700°F and 200 psi for the 3004-AS and 550°F and 100 psi for the PKHS-1 composites. Laminates made to these conditions were low-void content (< 2%) with good fiber collimation and good fiber distribution as shown in Figures 30 and 31. The graphite fibers were also well wetted as revealed by scanning election photomicrographs of the fiber/resin interface (Figures 32 and 33). Mechanical property tests on the laminates showed reasonably good composite properties (See Section 2.2.2) even though the resin content of the 3004 AS composites were higher than anticipated. The 3004 AS was purchased with a nominal resin content of 32% but variations in the prepreg and resin rich areas, resulted in some laminates with a resin content of 40-42% by weight. This large variation could be attributed to the fact that 3004 was an experimental prepreg run and may not have been optimized.
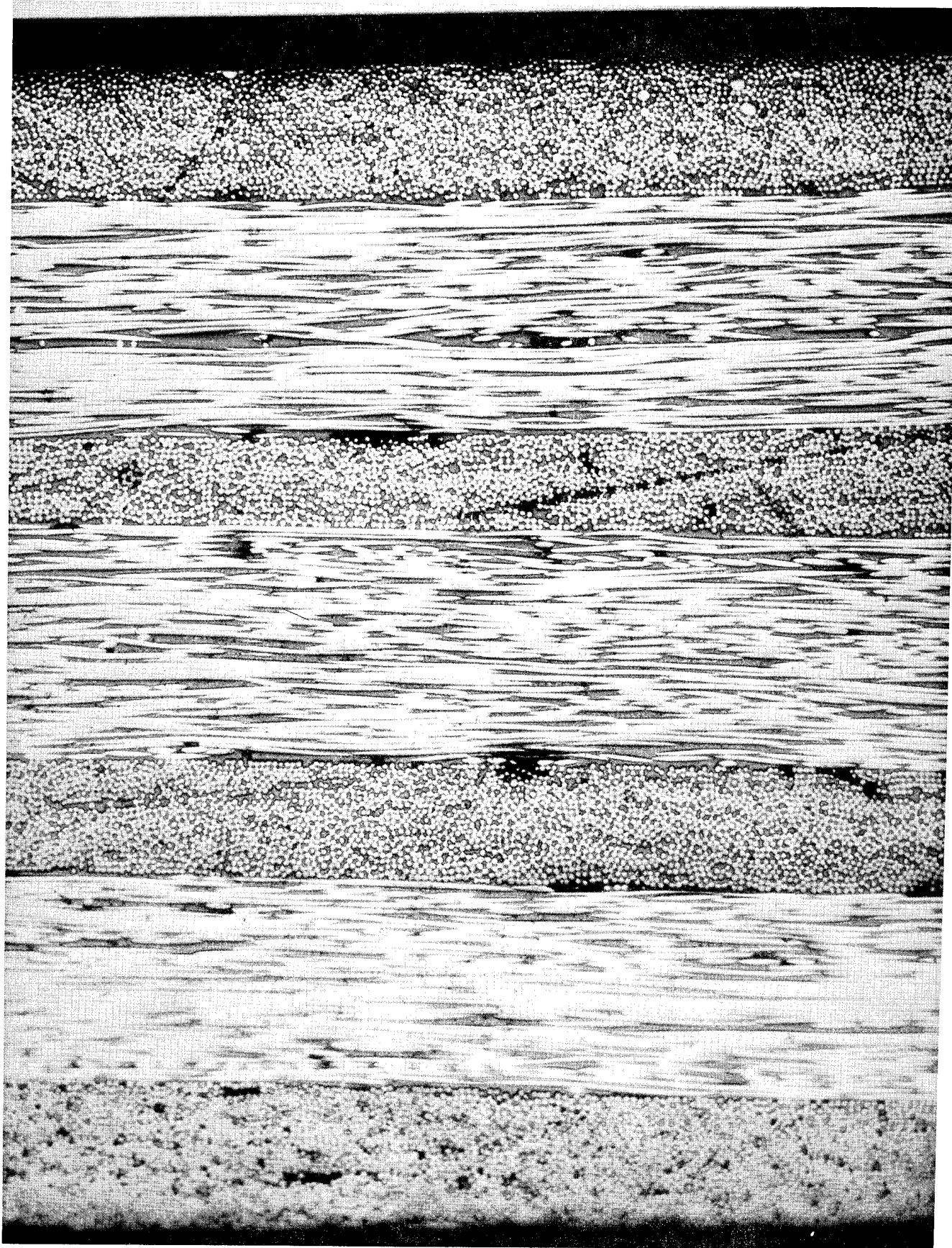
FIGURE 30   PKHS-1/AS GRAPHITE COMPOSITE − 0° - 90° (65X)

51
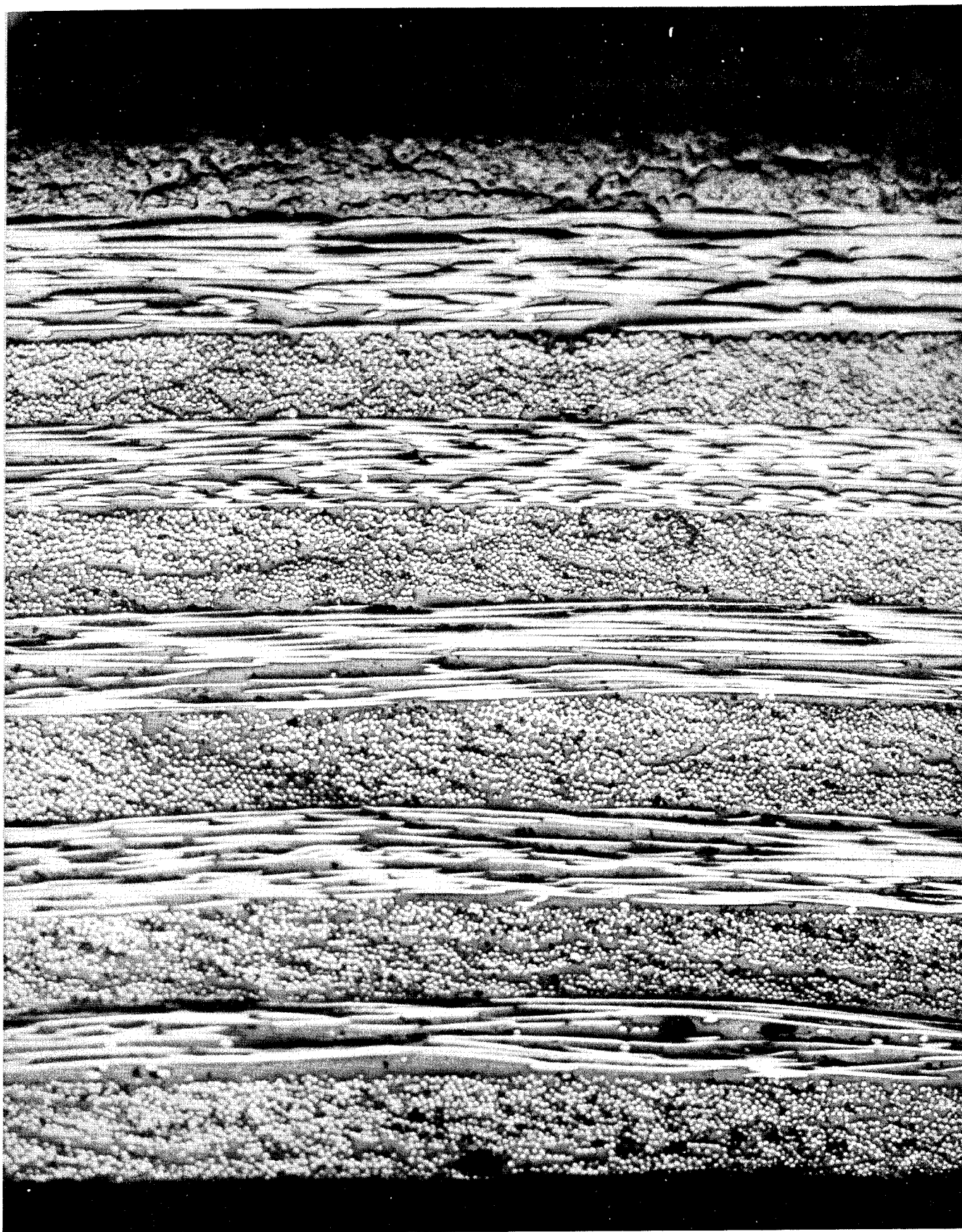
FIGURE 31   3004/AS GRAPHITE COMPOSITE – 0⁰ – 90⁰ (65X)

FIGURE 32   SCANNING ELECTRON PHOTOMICROGRAPH OF A GRAPHITE/
POLYSULFONE COMPOSITE (500X)

53

FIGURE 33   SCANNING ELECTRON PHOTOMICROGRAPH OF A GRAPHITE/
PHENOXY COMPOSITE (500X)

2.2.1 (Continued)

A series of 3004 AS/graphite composites was fabricated at different temperatures and pressures to determine if the properties could be improved. Of specific interest was the effect of increased laminating pressure on the properties; namely, inter-laminar shear. The parameters used and the properties obtained on each laminate are shown in Tables 7 and 8. The results of the study (Tables 7 and 8) showed that the properties of the thermoplastic laminates could not be substantially improved by laminating at higher pressures at a given temperature. However, the quality, void content, and uniformity of the composite were affected by increased laminating pressure as shown in Figures 34 and 35. These two laminates were both molded at 600°F but one under 500 psi and the other under 1000 psi. It was found that the temperature of lamination must be above about +550°F to achieve good flow and uniform quality. This is evident by comparing the laminate shown in Figure 36, molded at 500°F and 1580 psi, to the laminates in either Figure 35 or 37, which were molded at 600°F and 1000°F and 700°F and 200 psi, respectively. The laminate molded at 500°F had a significant number of voids even though the com-paction was good.

In selecting the laminating parameters, a balance must be made between temperature and pressure. The selected temperature must be high enough to impart good flow in the resin to facilitate wetting, yet as low as possible to minimize oxidation and for ease of handling. The pressure must be adjusted to the selected temperature. It is desirable from facility and practical standpoints to maintain the pressure as low as possible, but still achieve compaction. If the pressure is too high for a given temperature, the high viscosity of the polymer will cause excessive fiber washing and distortion which is undesirable. It does appear, based on these limited studies, that there is considerable leeway on the number of temperature/pressure combinations one can use and still achieve a quality part. The particular combination used would be governed more by the facilities available, type of component being manufactured, and the manufacturing technique being employed.

TABLE 7   EFFECT OF PROCESSING ON THE FLEXURAL STRENGTH AND MODULUS – UNIDIRECTIONAL GRAPHITE LAMINATES

MATERIAL	PANEL NO.	SPEC. NO.	SPEC. DIMEN. IN. THK.	SPEC. DIMEN. IN. WIDTH	TEST TEMP.	LOAD, lbs.	STRENGTH, 10^3 PSI	MODULUS, 10^6 PSI	PROCESS VARIABLES
POLYSULFONE (3004 AS)	45	1	.093	.505	-65°F	334	172	10.9	(700°F & 200 psi)
		2	.093	.507	→	378	194	10.7	
		3	.093	.505		345	178	10.9	
							(181)	(10.8)	
		4	.093	.503	70°F	333	172	11.3	
		5	.093	.505	→	326	168	11.3	
		6	.093	.505		323	166	10.9	
							(169)	(11.3)	
		7	.093	.506	180°F	258	133	10.2	
		8	.093	.501	→	275	143	11.2	
		9	.093	.505		270	139	11.1	
							(138)	(10.8)	
		10	.093	.504	350°F	25.0	12.9	.50	
		11	.093	.505	→	28.8	14.8	.83	
		12	.092	.492		33.7	18.2	4.85	
							(15.3)	(2.06)	
	47	1	.091	.508	70°F	285	152	5.08	(600°F & 500 psi)
		2	.092	.506	→	298	157	5.79	
		3	.092	.506		300	158	5.79	
							(156)	(5.55)	
	48	1	.091	.507	70°F	323	173	13.0	(600°F & 1000 psi)
		2	.092	.507	→	322	169	13.1	
		3	.089	.505		317	178	12.9	
							(173)	(13.0)	
	50	1	.090	.504	70°F	330	182	13.6	(500°F & 1500 psi)
		2	.090	.503	→	293	162	12.8	
		3	.091	.507		325	174	13.0	
							(173)	(13.1)	

56

TABLE 7 EFFECTS OF PROCESSING ON THE FLEXURAL STRENGTH AND MODULUS – UNIDIRECTIONAL GRAPHITE LAMINATES (Con't)

MATERIAL	PANEL NO.	SPEC. NO.	SPEC. DIMEN. IN. THK.	WIDTH	TEST TEMP.	LOAD. lbs.	STRENGTH. 10^3 PSI	MODULUS. 10^6 PSI	PROCESS VARIABLES
PHENOXY	61	1	.152	.528	70°F	388	143	13.4	(600°F & 100 psi)
(PKHS-1/AS)		2	.154	.529	→	389	140	13.0	
		3	.152	.526		402	151	12.5	
							(145)	(13.0)	
	65	1	.070	.506	-65°F	265	241	13.4	
		2	.065	.503	→	257	272	15.5	
		3	.072	.498		249	217	13.0	
							(243)	(14.0)	
		4	.073	.503	70°F	208	175	13.2	
		5	.068	.508	→	189	181	14.4	
		6	.073	.496		213	181	13.4	
							(179)	(13.7)	
		7	.065	.506	180°F	96.8	102	11.2	
		8	.068	.497	→	139	136	12.1	
		9	.067	.498		143	143	12.2	
							(127)	(11.8)	

△1 3.0" Span: All others were 1.5" span.

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57

TABLE 8 — EFFECTS OF PROCESSING ON THE INTERLAMINAR SHEAR STRENGTH OF UNIDIRECTIONAL GRAPHITE LAMINATES

MATERIAL	PANEL NO.	SPEC. NO.	SPEC. DIMEN., IN. THK.	WIDTH	TEST TEMP.	LOAD, lbs.	STRENGTH, 10^3 PSI	PROCESS VARIABLES
POLYSULFONE (3004 AS)	45	1	.092	.254	-65°F	410	13.16	(700°F - 200 psi)
		2	.093	.262	↓	433	13.33	
		3	.092	.256	↓	431	13.73	
							(13.40)	
		4	.091	.255	70°F	335	10.83	
		5	.093	.260	↓	363	11.26	
		6	.092	.253	↓	340	10.96	
							(11.02)	
		7	.093	.258	180°F	297	9.29	
		8	.092	.256	↓	285	9.08	
		9	.093	.256	↓	276	8.69	
							(9.02)	
		10	.093	.255	350°F	---	---	
		11	.092	.257	↓	115	3.65	
		12	.092	.255	↓	70	2.24	↓
							(2.94)	
	47	1	.090	.259	70°F	295	9.50	(600°F - 500 psi)
		2	.090	.258	↓	325	10.50	
		3	.091	.258	↓	310	9.90	↓
							(9.97)	
	48	1	.091	.257		280	8.98	(600°F - 1000 psi)
		2	.091	.257		272	8.72	
		3	.090	.258		320	10.34	↓
							(9.35)	
	50	1	.092	.258		277	8.75	(500°F - 1580 psi)
		2	.091	.260		280	8.87	↓
		3	.090	.262	↓	281	8.94	
							(8.86)	

MATERIAL	PANEL NO.	SPEC. NO.	SPEC. DIMEN., IN.		TEST TEMP.	LOAD, lbs.	STRENGTH, 10^3 PSI		PROCESS VARIABLES
			THK.	WIDTH					
PHENOXY	61	1	.148	.271	−65°F	790	14.80		(600°F – 100 psi)
(PKHS-1)		2	.153	.273	↓	780	13.90		
		3	.150	.281	↓	745	13.30		
							(14.0)		
		4	.148	.265	70°F	534	10.2		
		5	.149	.283	↓	539	9.59		
		6	.151	.282	↓	547	9.63		
							(9.81)		
		7	.156	.278	180°F	278	4.81		
		8	.155	.269	↓	355	6.39		
		9	.156	.272	↓	379	6.70		
							(5.97)		

TABLE 8   EFFECTS OF PROCESSING ON THE INTERLAMINAR SHEAR STRENGTH OF UNIDIRECTIONAL GRAPHITE LAMINATES (Con't)
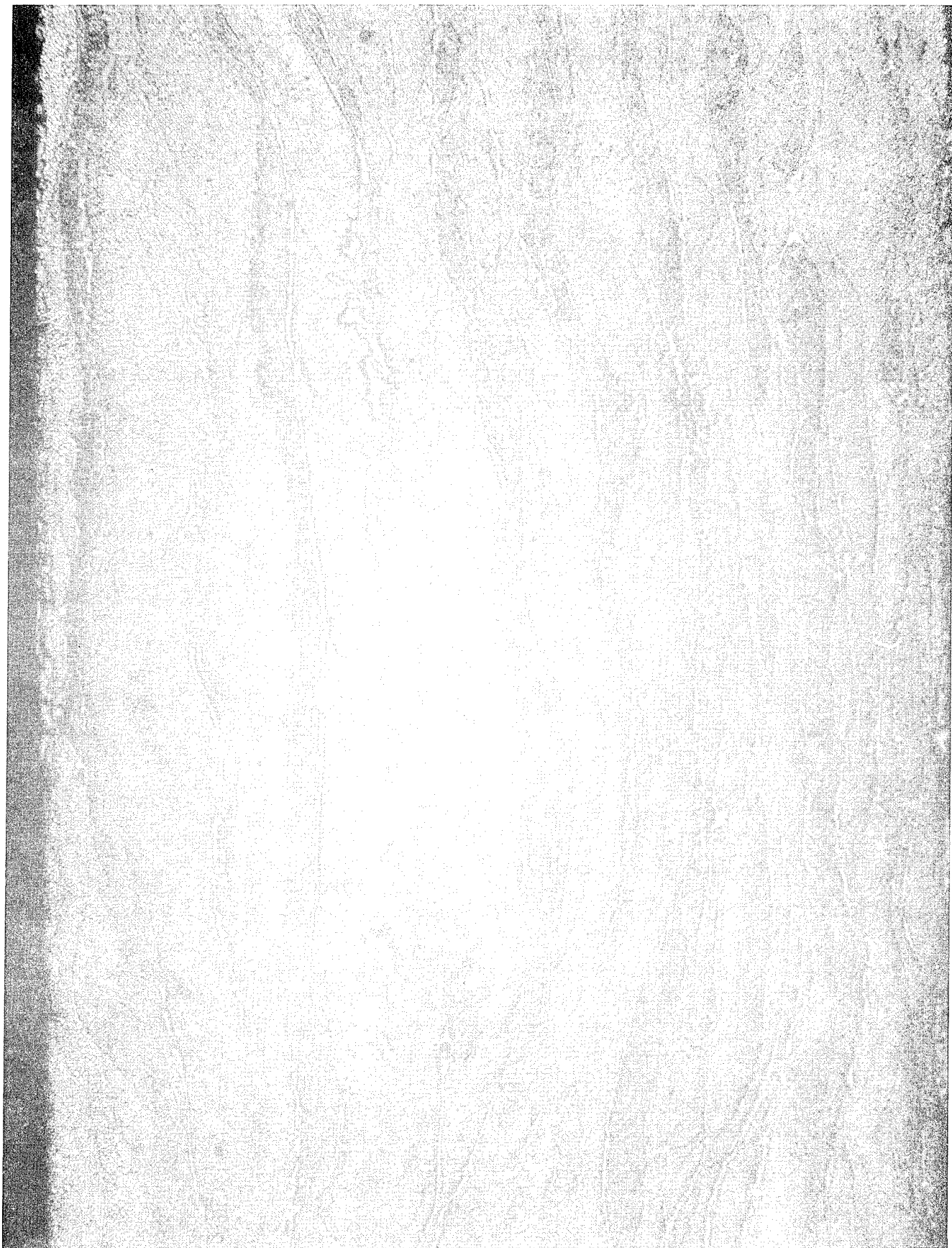
FIGURE 34   GRAPHITE REINFORCED POLYSULFONE COMPOSITE CROSS SECTION-
3004 AS (30X)   [600°F, 500 psi]
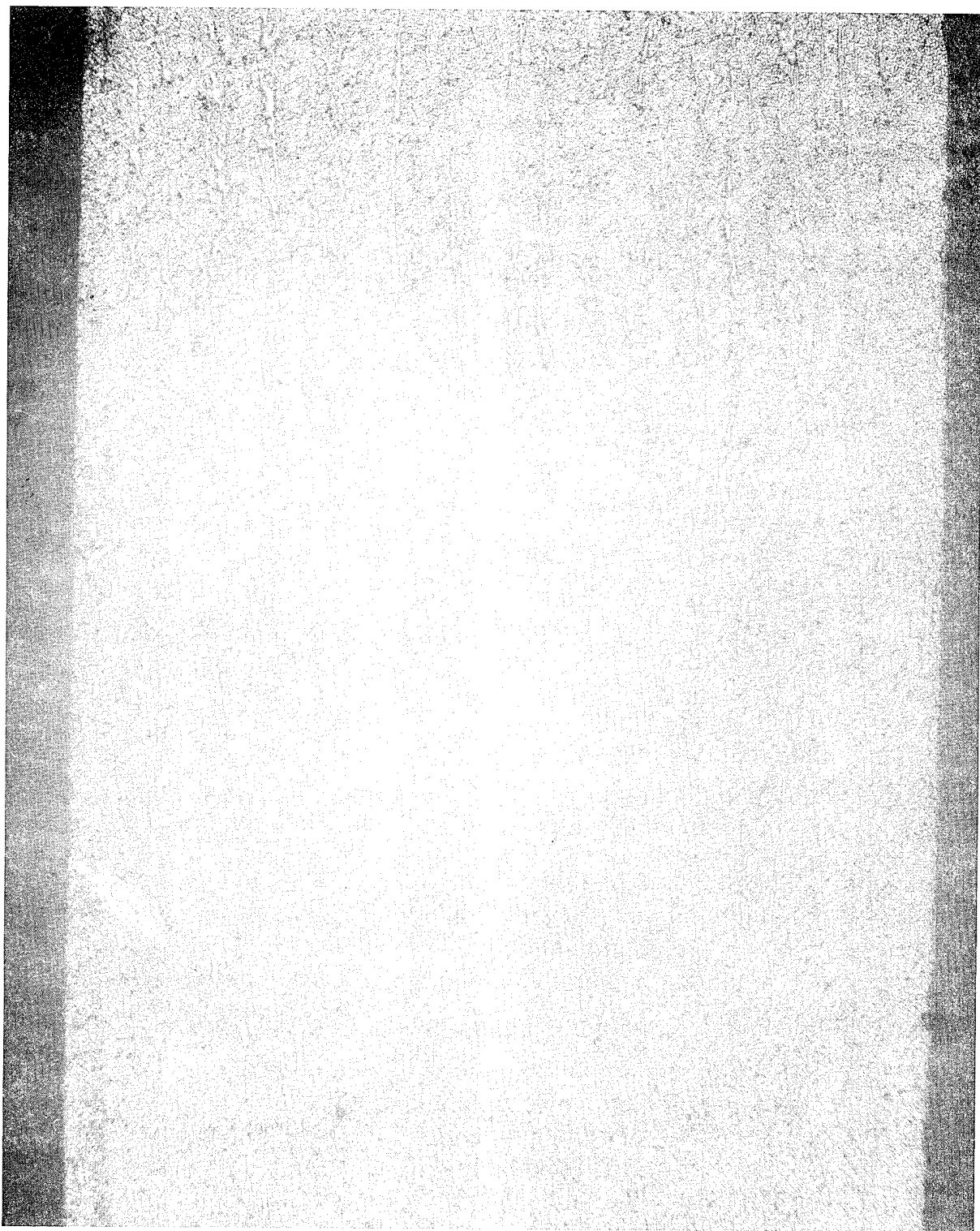
FIGURE 35 GRAPHITE REINFORCED POLYSULFONE COMPOSITE CROSS SECTION 3004-AS (30X) [600°F, 1000 psi]
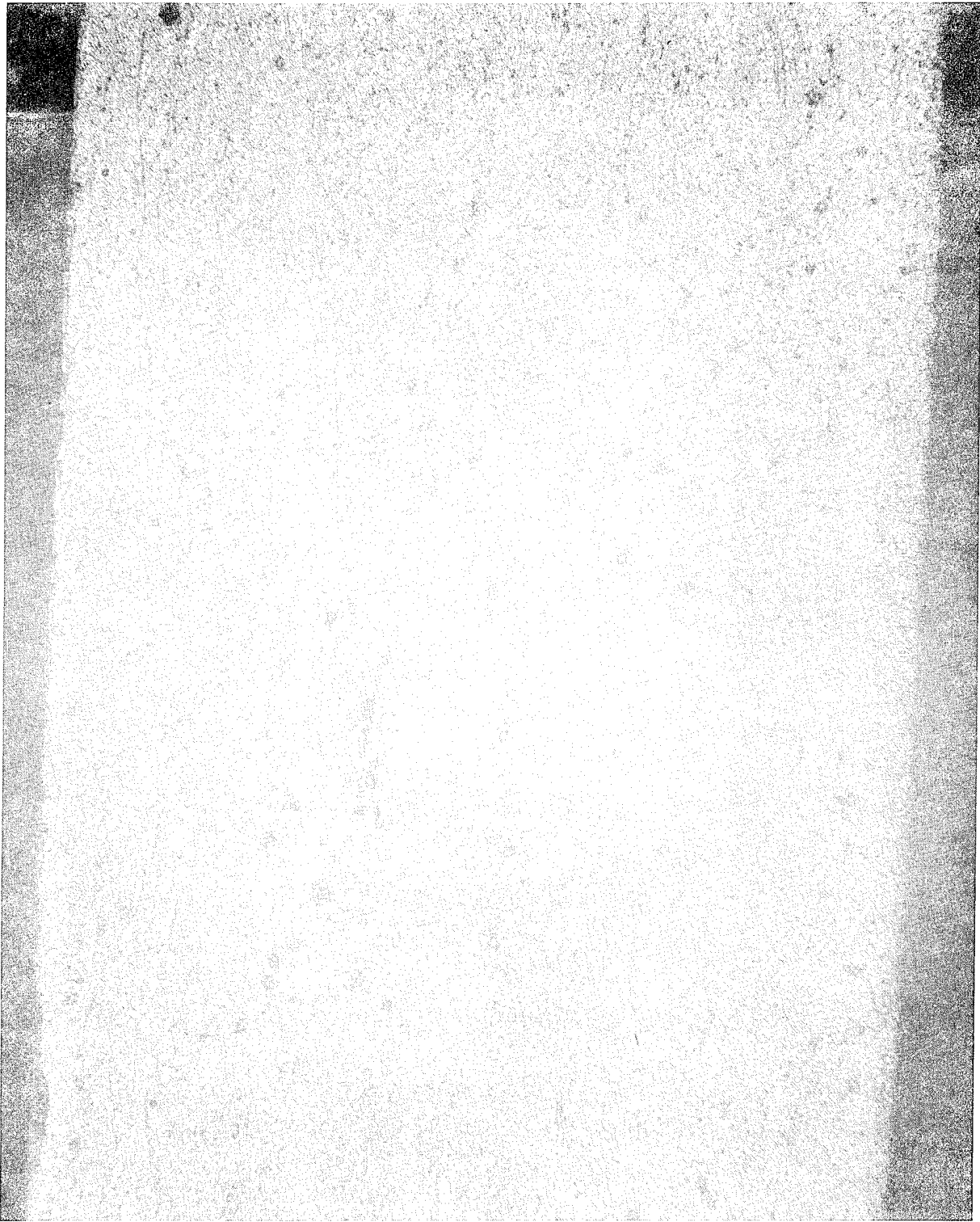
FIGURE 36 GRAPHITE REINFORCED POLYSULFONE COMPOSITE CROSS SECTION 3004 - AS (30X) [500°F, 1580 psi]
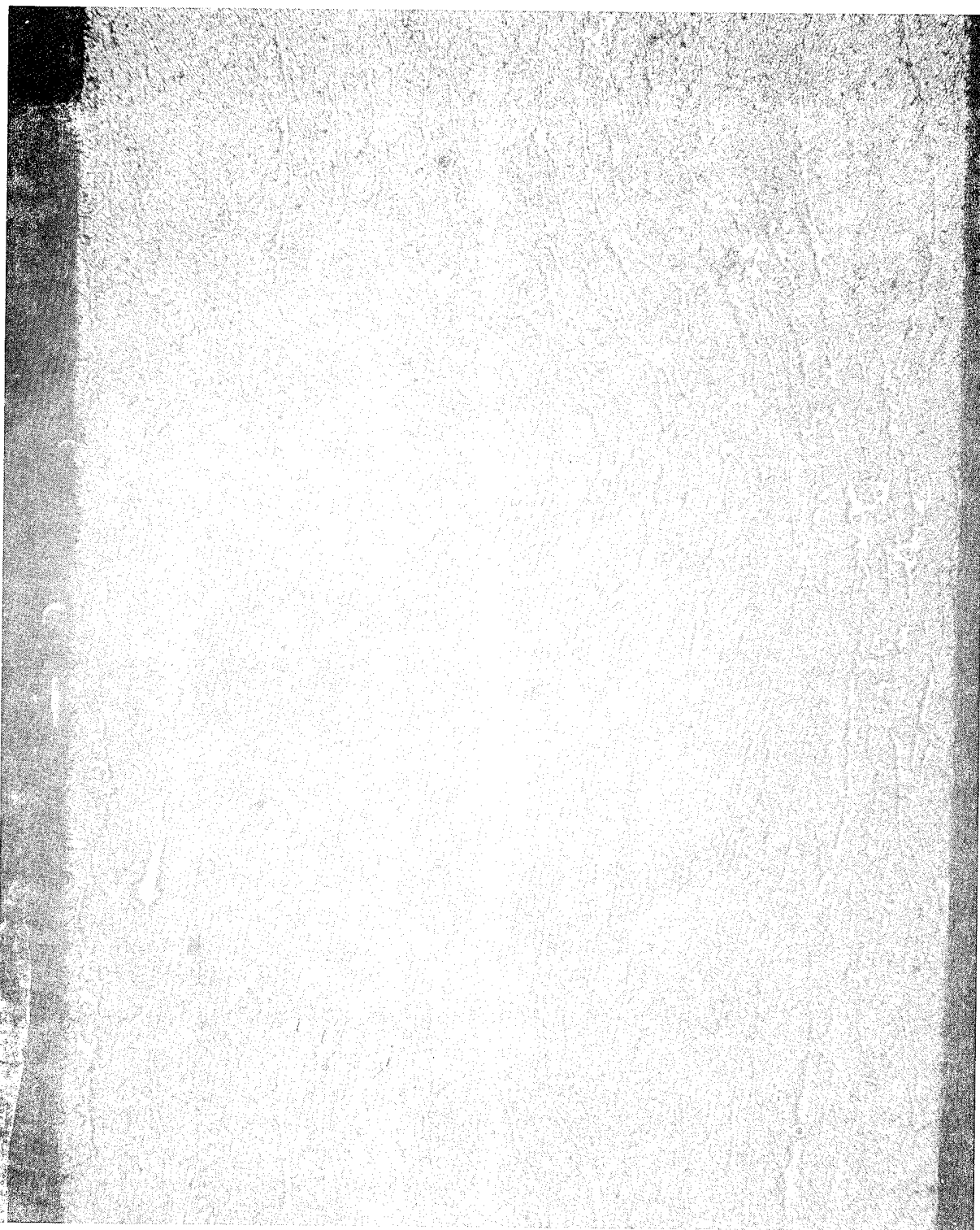
FIGURE 37 GRAPHITE REINFORCED POLYSULFONE COMPOSITE CROSS SECTION 3004–
AS (30X) [700°F, 200 psi]

2.2.2 PROPERTY INVESTIGATION

The mechanical properties of 3004, PKHS-1, and epoxy, unidirectional graphite composites at +70°F are given in Figures 38 and 39. Additional data showing the flexural strength and modulus and the interlaminar shear strength as a function of temperature is shown in Figures 40 and 41, respectively.

The thermoplastic resins with glass reinforcement exhibited a substantial increase in impact strength over the epoxy laminates (Section 3.1.2) when tested in this program. Tests were conducted on the graphite reinforced thermoplastic laminates to assess whether or not similar increases could be achieved since the low impact strength of graphite/epoxy composites has been a serious problem in many applications. A composite of X3501/A-S graphite epoxy and X3501/HMS graphite epoxy was tested for comparisons. The results, shown in Figure 42, indicate that a 50% increase in impact strength can be achieved. These results are similar to the improvements realized with glass reinforcement.

A second problem that has arisen frequently with graphite epoxy composites is microcracking of the matrix, especially in a rapidly changing thermal environment (i.e., thermal shock). The thermoplastic polymers are, in general, fairly resistant to thermal shock and could possibly offer improvement in this area. A 0° - 90° crossplied graphite laminate was fabricated from 3004 A-S graphite prepreg and evaluated for thermal shock characteristics. The laminate was photographed prior to exposure and then cycled 100 times between -65°F and +250°F. Each cycle consisted of holding the specimen for three minutes at -65°F (alcohol and dry ice bath) and then immediately submerging it in a +250°F tube furnace where it was again held for three minutes to allow the specimen to come to equilibrium. After repeating the cycle 100 times, the specimen was again photographed to detect any microcracks. The before and after photos, shown in Figures 31 and 43, respectively, reveal no change or evidence of microcracking.
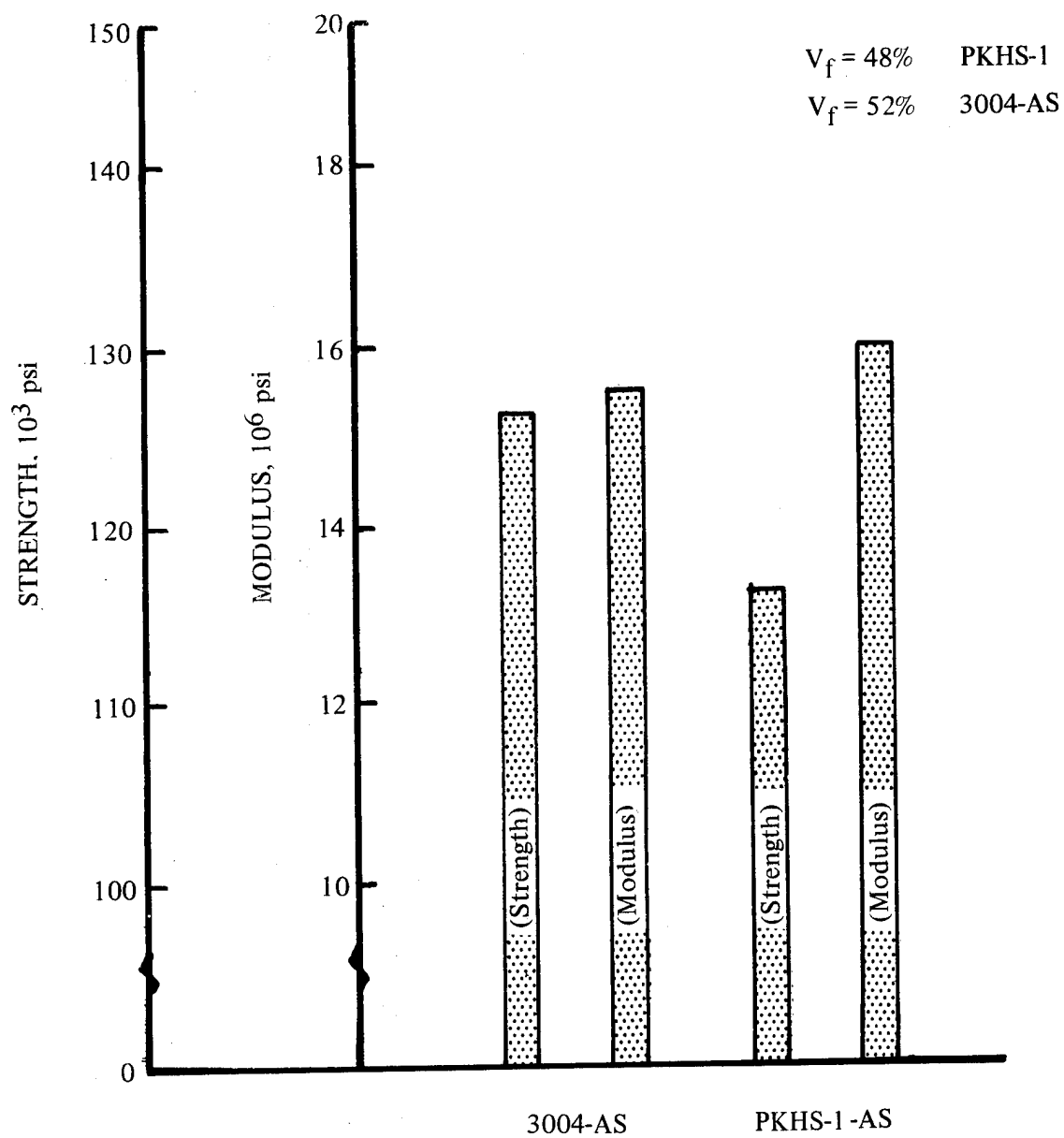
FIGURE 39 COMPRESSIVE PROPERTIES OF UNIDIRECTIONAL
GRAPHITE COMPOSITES

66
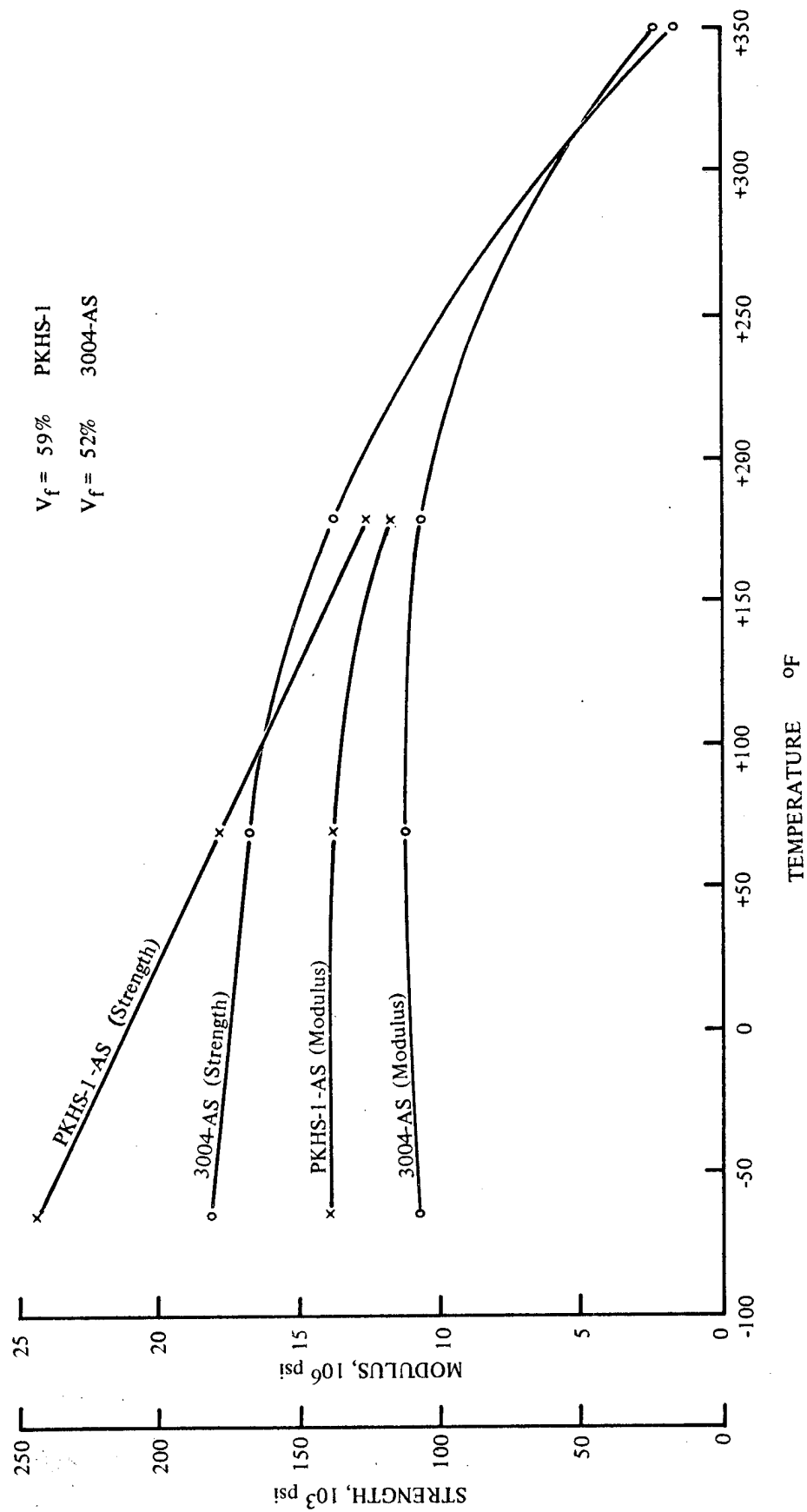
FIGURE 40 FLEXURAL PROPERTIES OF UNIDIRECTIONAL GRAPHITE LAMINATES VS. TEMPERATURE

$V_f = 59\%$ PKHS-1
$V_f = 52\%$ 3004-AS

PKHS-1-AS (Strength)
3004-AS (Strength)
PKHS-1 -AS (Modulus)
3004-AS (Modulus)

TEMPERATURE °F

MODULUS, 10^6 psi

STRENGTH, 10^3 psi
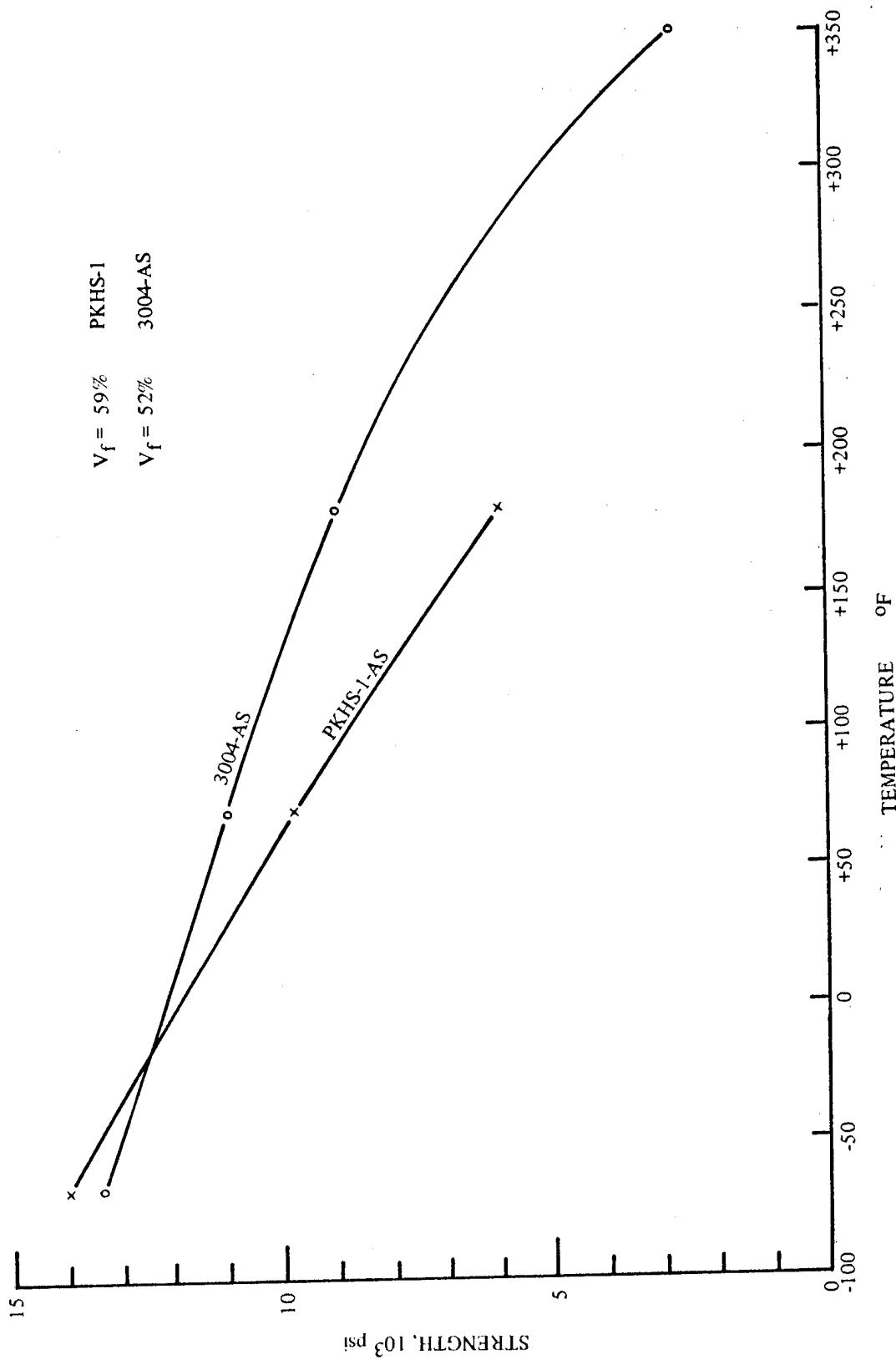
FIGURE 41   INTERLAMINAR SHEAR STRENGTH OF UNIDIRECTIONAL GRAPHITE
LAMINATES VS. TEMPERATURE

68
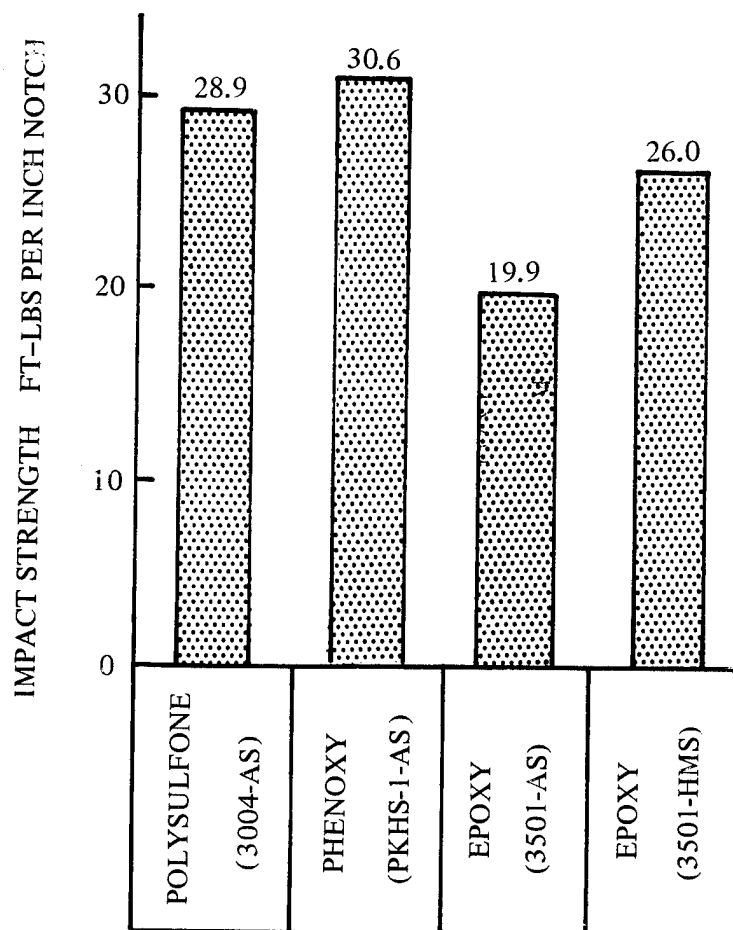
FIGURE 42   IZOD IMPACT STRENGTH (NOTCHED) OF
UNIDIRECTIONAL GRAPHITE LAMINATES

2.3   PHASE III - MANUFACTURING METHODS AND COST ASSESSMENT

2.3.1   MANUFACTURING METHODS

The laminates fabricated in Phases I and II were press molded. This mode of processing is well suited for rapid production of flat panels and small contoured parts. However, it is an impractical process for many structural components which are more suited to an autoclave process. In this phase of the program a study was made to determine if equivalent quality laminates could be made by either a press or autoclave process using similar temperature and pressure requirements.

A 10-ply P-1700/181 glass fabric laminate was bagged and autoclaved. Laminating conditions were 650°F, 200 psi with a 3°/minute rise to temperature, a 15-minute hold at temperature, followed by a 3°/minute decline in temperature. (The 3°/minute rise in temperature was the limitation of the autoclave used.) The laminate was bagged on a steel plate using titanium caul sheets top and bottom, and a Kapton film bag. Vacuum was maintained on the laminate during the entire cycle. Upon removal from the autoclave, the laminate (Panel 41, Table 9) had the same appearance and clarity as the press made laminates (Panel 46, Table 9) and had the natural absence of edge oxidation which one experiences with a press laminate. The laminate was evaluated for flexural strength and modulus and interlamina shear and was found comparable to the pressed laminates (Tables 9 and 10). Based on the ease of fabrication, the autoclave process was used to make contoured parts as discussed below in Section 2.3.2.

Although the autoclave process of 650°F/200 psi produced good quality laminates, additional laminates were made to determine if the parameters could be lowered by possibly increasing the time at temperature. Two additional P-1700 laminates were made using the following sets of parameters:

        1. 600°F, 200 psi, 1 hour hold at temperature. (Panel No. 73)

        2. 550°F, 100 psi, 1 hour hold at temperature. (Panel No. 74)

The results of these tests are given in Tables 9 and 10.

TABLE 9   EFFECTS OF PROCESSING ON THE FLEXURAL STRENGTH AND MODULUS OF 181 GLASS FABRIC LAMINATES

MATERIAL	PANEL NO.	SPEC. NO.	SPEC. DIMEN., IN.		TEST TEMP.	LOAD, lbs.	STRENGTH, 10³ PSI	MODULUS, 10⁶ PSI	PROCESS VARIABLES
			THK.	WIDTH					
POLYSULFONE (P-1700)	46	1	.087	.491	70°F	54.5	66.0	3.57	Flat Press - 10 Ply
		2	.087	.496		56.0	67.1	3.45	(700°F - 200 psi)
		3	.085	.499		53.0	66.2	3.52	Flat Panel
							(66.1)	(3.51)	
	41	1	.088	.485		53.5	64.1	3.72	Autoclave - 10 Ply
		2	.091	.479		56.5	64.1	3.40	(650°F - 200 psi)
		3	.090	.484		60.5	69.4	3.54	Flat Panel
							(65.7)	(3.55)	
	73	1	.088	.497		60.0	70.2	3.43	Autoclave - 10 Ply
		2	.087	.499		59.5	71.4	3.59	(600°F - 200 psi)
		3	.087	.496		60.0	71.9	3.45	Flat Panel
							(71.2)	(3.49)	
	74	1	.088	.498		53.5	62.4	3.42	Autoclave - 10 Ply
		2	.088	.501		53.8	62.4	3.40	(550°F - 100 psi)
		3	.090	.501		55.0	61.0	3.31	Flat Panel
							(61.9)	(3.38)	
	43-1	1	.061	.486		26.8	66.7	4.05	Flat Press - 7 Ply
		2	.061	.485		26.8	66.8	4.01	(700°F - 200 psi)
		3	.061	.481		25.0	62.9	3.84	Flat Panel
							(65.5)	(3.97)	
	43-2	1	.055	.510		22.0	64.2	4.13	Post-Formed - 7 Ply
		2	.057	.515		26.7	71.8	4.29	(700°F - 200 psi)
		3	.051	.506		18.0	61.5	4.26	Corrugated Panel
		4	.056	.513		24.2	67.7	4.28	
							(66.3)	(4.24)	
	53	1	.052	.508		16.2	52.9	3.78	Match Die - 7 Ply
		2	.053	.506		19.8	62.7	4.48	(700°F - 200 psi)
		3	.052	.518		17.6	56.5	4.11	Corrugated Panel
							(57.4)	(4.12)	

TABLE 9   EFFECT OF PROCESSING ON THE FLEXURAL STRENGTH AND MODULUS OF 181 GLASS FABRIC LAMINATES (Con't)

MATERIAL	PANEL NO.	SPEC. NO.	SPEC. DIMEN., IN.		TEST TEMP.	LOAD, lbs.	STRENGTH, 10^3 PSI	MODULUS, 10^6 PSI	PROCESS VARIABLES
			THK.	WIDTH					
PHENOXY (PKHS-1)	51	1	.075	.488	70°F	50.0	82.0	4.26	Flat Press - 10 Ply
		2	.077	.485		45.5	71.2	4.27	(600°F - 100 psi)
		3	.077	.488		49.2	76.5	4.18	Flat Panel
							(76.6)	(4.24)	
	56	1	.093	.508		61.0	62.5	3.50	Autoclave - 10 Ply
		2	.092	.504		54.0	57.0	3.23	(550°F - 100 psi)
		3	.094	.506		56.4	56.8	3.12	Flat Panel
							(58.8)	(3.28)	
	52-1	1	.056	.489		25.5	74.8	4.42	Flat Press - 7 Ply
		2	.057	.490		24.3	68.7	4.02	(600°F - 100 psi)
		3	.055	.477		22.6	70.5	4.24	Flat Panel
							(71.3)	(4.23)	
	52-2	1	.047	.511		18.1	72.2	5.39	Post-Formed - 7 Ply
		2	.047	.517		18.6	73.3	5.37	(600°F - 100 psi)
		3	.047	.518		18.1	71.2	5.43	Corrugated Panel
							(72.2)	(5.40)	
	54	1	.051	.511		20.6	69.7	5.11	Match-Die - 7 Ply
		2	.050	.512		17.6	61.9	4.35	(600°F - 100 psi)
		3	.052	.507		20.6	67.6	4.90	Corrugated Panel
							(66.4)	(4.79)	
EPOXY (CONTROL)	1	1	.100	.513		81.0	71.1	3.21	Autoclave - 10 Ply
		2	.100	.513		81.5	71.5	3.13	(Standard Cure)
		3	.100	.517		82.0	71.4	3.23	Flat Panel
							(71.3)	(3.18)	
	42-3	1	.065	.510		35.3	78.5	4.04	Match-Die - 7 Ply
		2	.058	.520		28.5	73.3	3.96	(Autoclave - Std Cure)
		3	.067	.512		38.1	74.6	3.59	Corrugated Panel
							(75.5)	(3.86)	
	42-4	1	.063	.520		31.2	68.0	4.09	Open Face - 7 Ply
		2	.065	.519		32.9	67.5	3.36	(Autoclave - Std Cure)
		3	.069	.518		35.8	65.3	3.15	Corrugated Panel
							(66.9)	(3.53)	

4032 5/90 ORIG

MATERIAL	PANEL NO.	SPEC. NO.	SPEC. DIMEN. IN.		TEST TEMP.	LOAD, lbs.	STRENGTH, 10³ PSI	PROCESS VARIABLES
			THK.	WIDTH				
POLYSULFONE	29-2	1	.080	.276	70°F	207	7.03	Press – 10 Ply
(P-1700)	↓	2	.082	.273	↓	230	7.71	(700°F – 200 psi)
		3	.081	.272		215	7.32	Flat Panel
							(7.35)	
	41	1	.087	.262		226	7.74	Autoclave – 10 Ply
	↓	2	.091	.257		237	7.60	(650°F – 200 psi)
		3	.091	.257		245	7.86	"
							(7.73)	
	73	1	.088	.304		248	6.95	Autoclave – 10 Ply
	↓	2	.088	.302		257	7.25	(600°F – 200 psi)
		3	.089	.303		255	7.09	"
							(7.10)	
	74	1	.091	.306		230	6.19	Autoclave – 10 Ply
		2	.090	.307		225	6.11	(550°F – 100 psi)
↓	↓	3	.089	.308		232	6.35	
							(6.22)	
PHENOXY	28-1	1	.083	.262		220	7.59	Flat-Press – 10 Ply
(PKHS-1)	↓	2	.082	.265		220	7.59	(470°F – 200 psi)
		3	.082	.267		230	7.88	"
							(7.69)	
	56	1	.093	.262		255	7.85	Autoclave – 10 Ply
	↓	2	.093	.262		258	7.94	(550°F – 100 psi)
↓		3	.086	.265	↓	238	7.83	
							(7.87)	

TABLE 10   EFFECT OF PROCESSING ON THE INTERLAMINAR SHEAR STRENGTH 181 GLASS FABRIC LAMINATES

An autoclave PKHS-1 glass/fabric laminate was made using conditions of 550°F and 100 psi (Panel 56, Table 9) and its properties were also comparable to a similar press molded laminate (Panel 23-1). The flexural properties and interlaminar shear strengths of these two panels are given in Tables 9 and 10.

The autoclave tests concluded that similar quality laminates could be made in either a press or an autoclave and molded using approximately the same parameters. As with the press molded laminates, there is a minimum temperature requirement in an autoclave associated with the lamination process. Above the critical temperature (550°F for P-1700), it appears that the lamination temperature has little influence on properties, while, if lamination occurs below the critical temperature, poor wetting occurs and properties drop off significantly. The temperature may also have an effect on the crystalline structure of the polymer, but this fact was not established. Generally, the autoclave process appears to make a better laminate in appearance due to the lack of oxidation in the fringe areas.

2.3.2 POST-FORMING

One of the most attractive features of reinforced thermoplastics from the manufacturing viewpoint is its heat-forming capability. With the post-forming concept, flat sheet stock with the desired fiber orientation, resin content, and thickness is fabricated or purchased from a supplier. Then with the use of a matched-metal die or an open mold, components are molded or autoclaved from the flat sheet under heat and pressure. To demonstrate the feasibility of fabricating structural elements by this method, several complex contours were heat-formed from 7-ply P-1700 and PKHS-1 glass fabric laminates and compared to conventional epoxy reinforced composites based on structural integrity. Portions of the post-formed P-1700 panel (Panel No. 43-2, Table 9) and the PKHS-1 (Panel No. 52-2, Table 9) are shown in Figures 44 and 45, respectively.

To provide additional processing information, components were matched-die molded from prepreg fabric using conventional procedures, and these were compared in quality and structural integrity to the corresponding post-formed parts. The matched die molded corrugated panels are No. 52 and 54 in Table 9. A portion of PKHS-1 matched-die molded panel is shown in Figure 46. There is no visual dissimilarity between it and a post-formed part.

AFTER THERMAL SHOCK
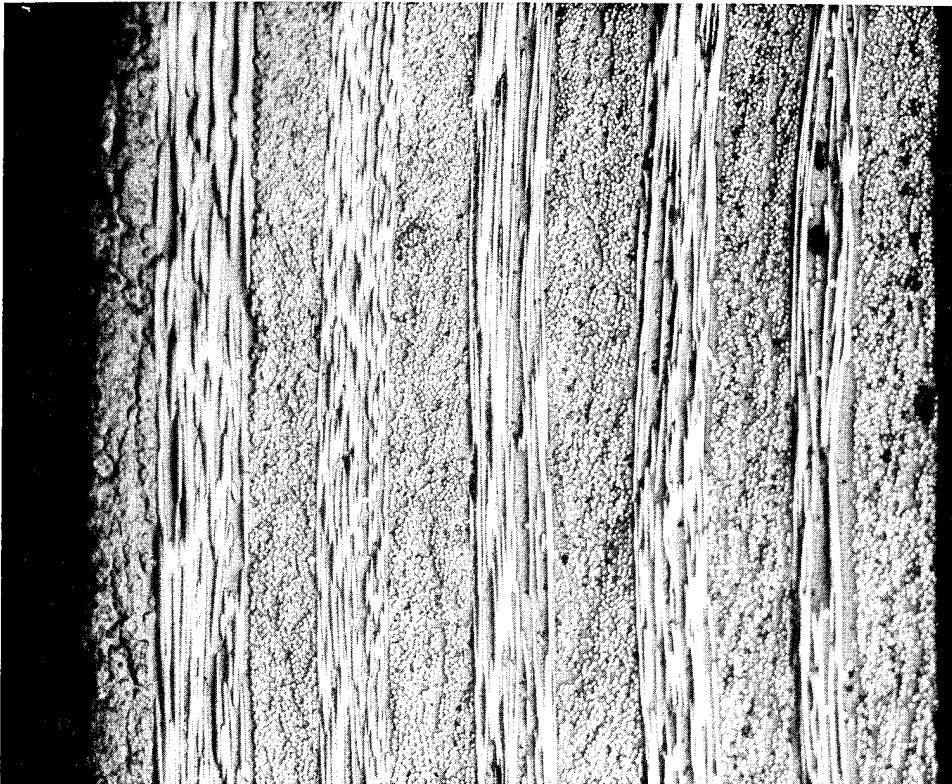
BEFORE THERMAL SHOCK
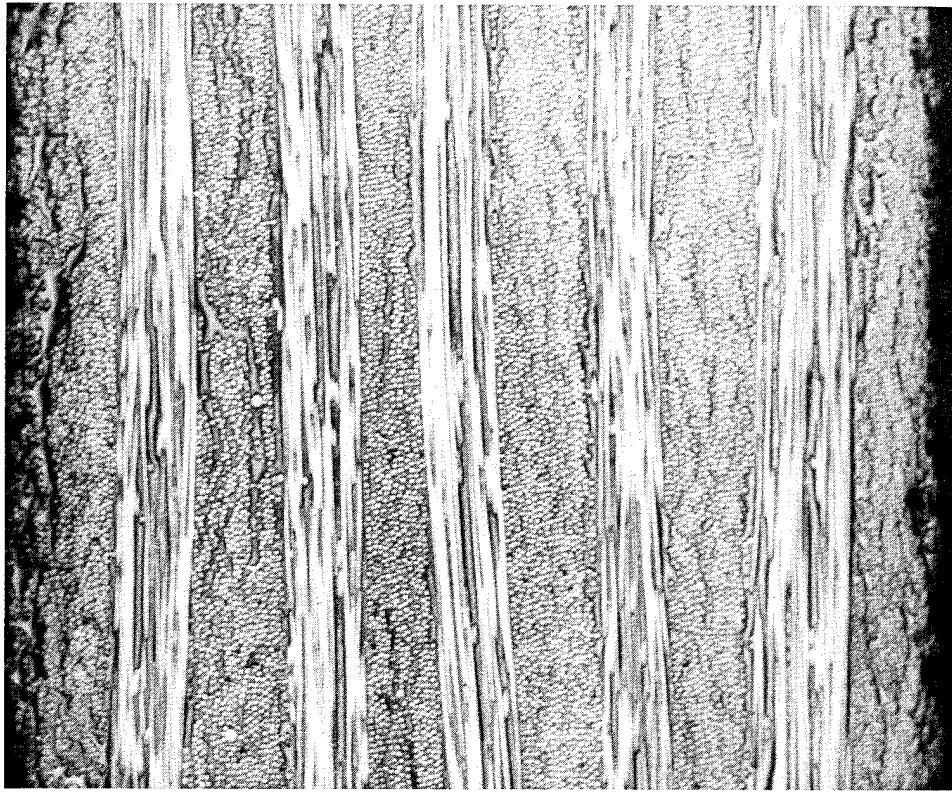
FIGURE 43: CROSS-PLIED 3004-AS GRAPHITE COMPOSITE BEFORE AND AFTER THERMAL SHOCK

75
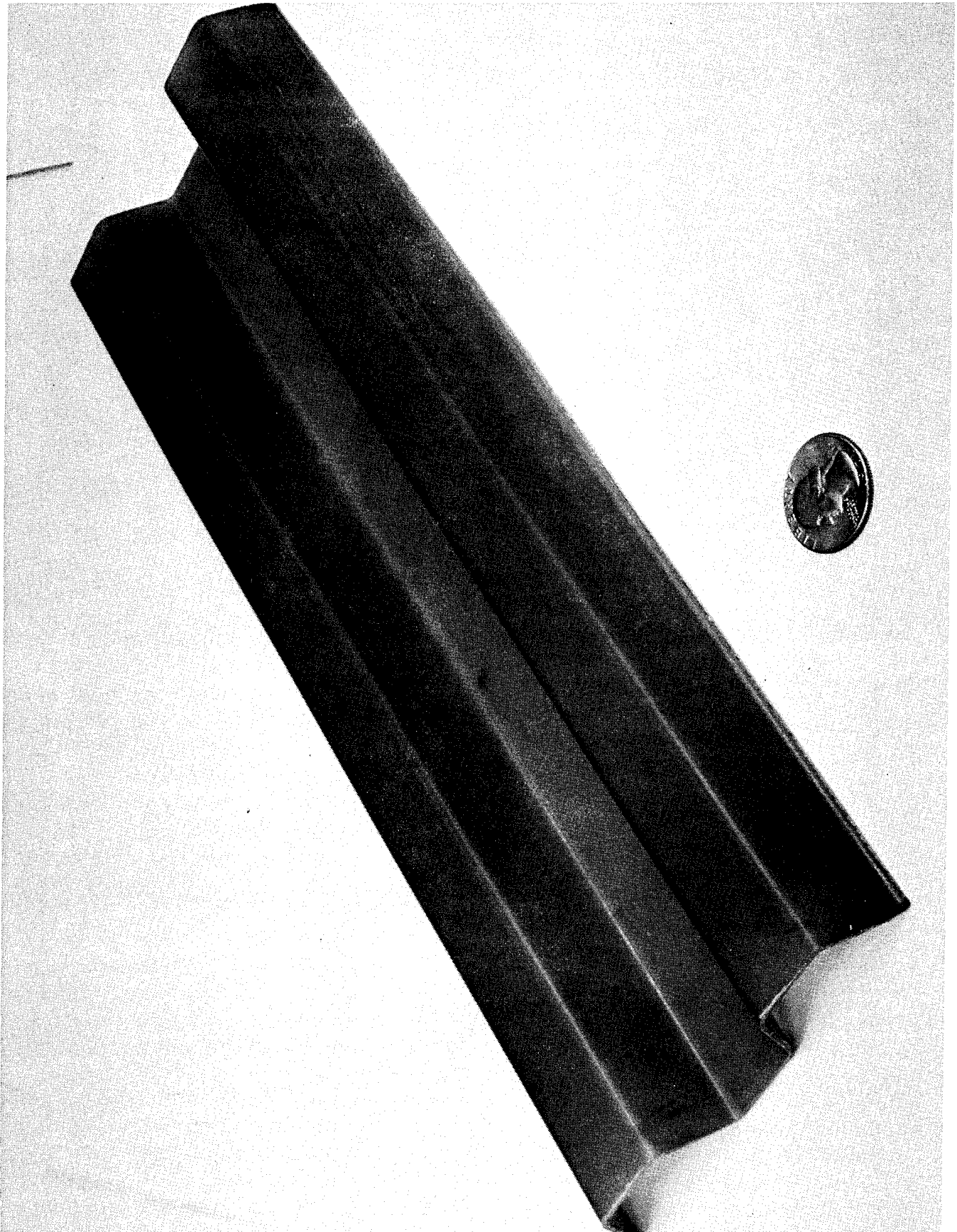
FIGURE 44   POST-FORMED CORRUGATED PANEL – P-1700/181 GLASS FABRIC
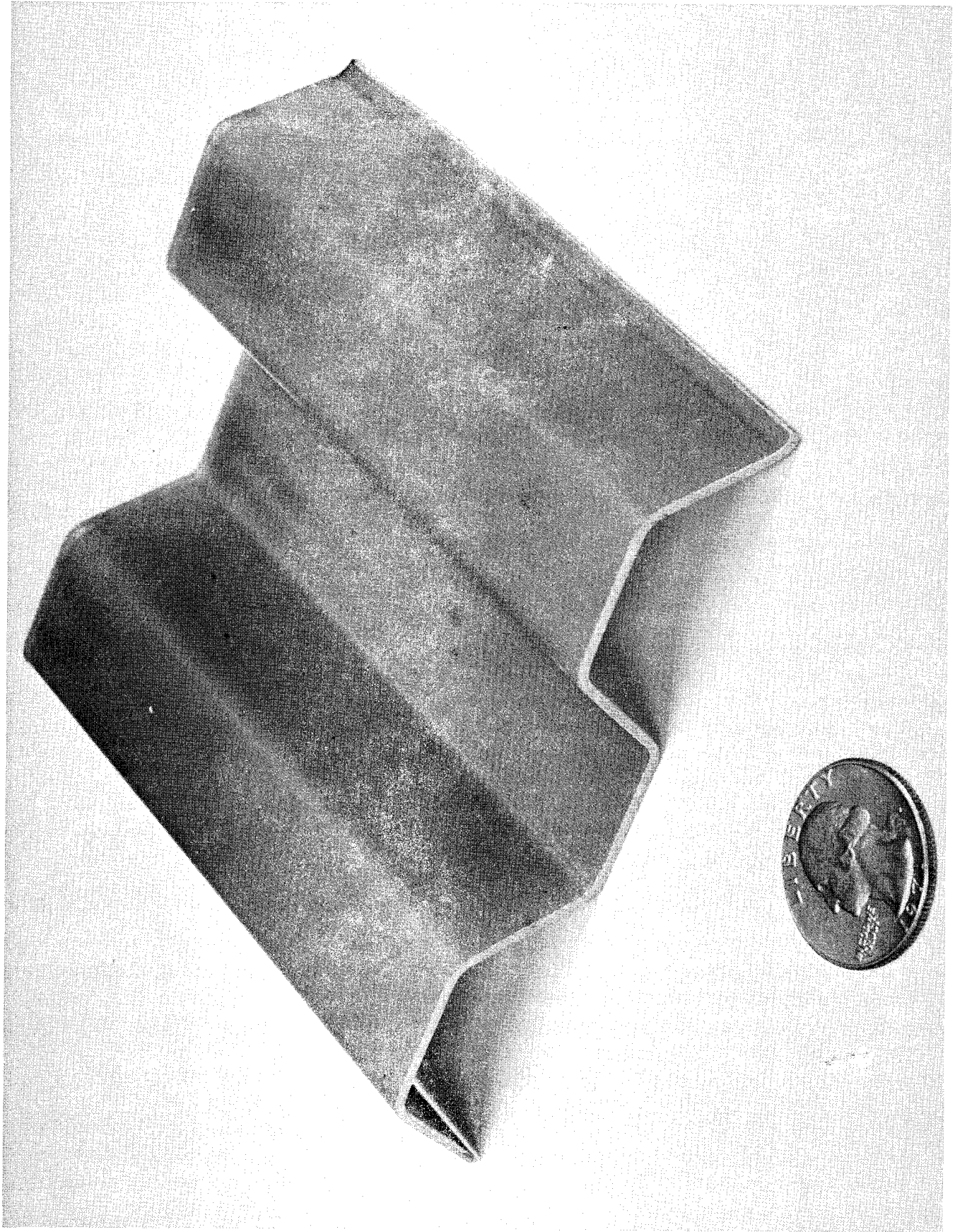
FIGURE 45   POST-FORMED CORRUGATED PANEL – PKHS-1/181 GLASS FABRIC
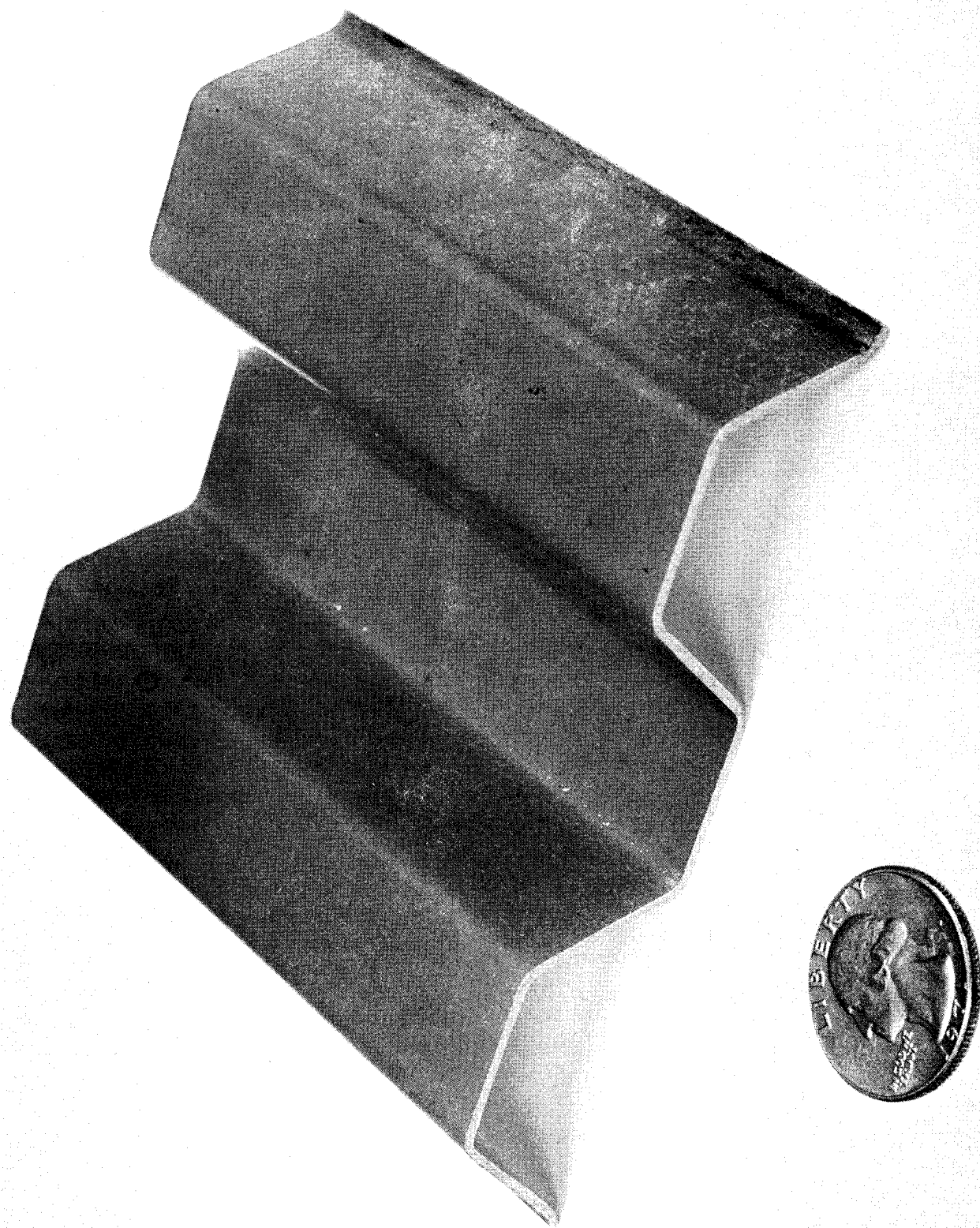
FIGURE 46   MATCHED-DIE MOLDED CORRUGATED PANEL – PKHS-1/181 GLASS FABRIC

The post-formed P-1700 corrugated panels were made using a cycle of 20 minutes at 700°F under 200 psi with a 3°F/minute temperature rise and decline with the laminate being inserted into a hot mold. The same cycle was used in the press matched die mold panels to maintain continuity. The PKHS-1 panels were post-formed (Panel 52-2) and matched-die molded (Panel 54) in the same manner, but at a temperature of 600°F and a pressure of 100 psi.

The corrugated panels for both systems made by either the post-formed or matched-die molded process had the same degree of compaction, clarity and strength. Strength quality of the corrugated panels was determined by testing each panel in axial compression using the type of specimen shown in Figure 47. The results of the compression tests are given in Figure 48.

Flexural specimens were cut from the flat portions of the corrugated panels after post-forming (Panels 43-2 and 52-2) and tested in flexure. These results were compared to the flexural strength of the laminate prior to post-forming (Panels 43-1 and 52-1) to assess the effects post-forming had on laminate quality. These comparative results are presented in Table 9. The combined result of the compression tests of the corrugated panels and the flexure tests of coupons from the panels indicate that post-forming does not degrade the quality of the laminate and that post-forming is a very viable process for structural components. Similar quality laminates can be molded directly from the prepreg if desired as illustrated by Panels 53 and 54. Also the quality of the corrugated panels, made by either process, was equivalent to those panels made with an epoxy -181 glass prepreg by conventional autoclaving techniques (see Table 9, Panels 1, 42-3, 42-4).

Another series of corrugated panels were post-formed (in a matched-die mold) from a 0° -90° graphite reinforced panel. The panels were post-formed using the same forming cycle and temperature used with the glass reinforcement. The post-formed 3004 AS graphite panel is shown in Figure 49. No fiber damage or fiber washing resulted from the post-forming operation. The 1/8" radius corners of the corrugations did not experience any gage reduction which is sometimes common with autoclaved thermoset laminates (see Figures 50 and 51.). These panels were also tested in axial compression and the results are shown in Figure 48. Also shown in Figure 48 are the results of an
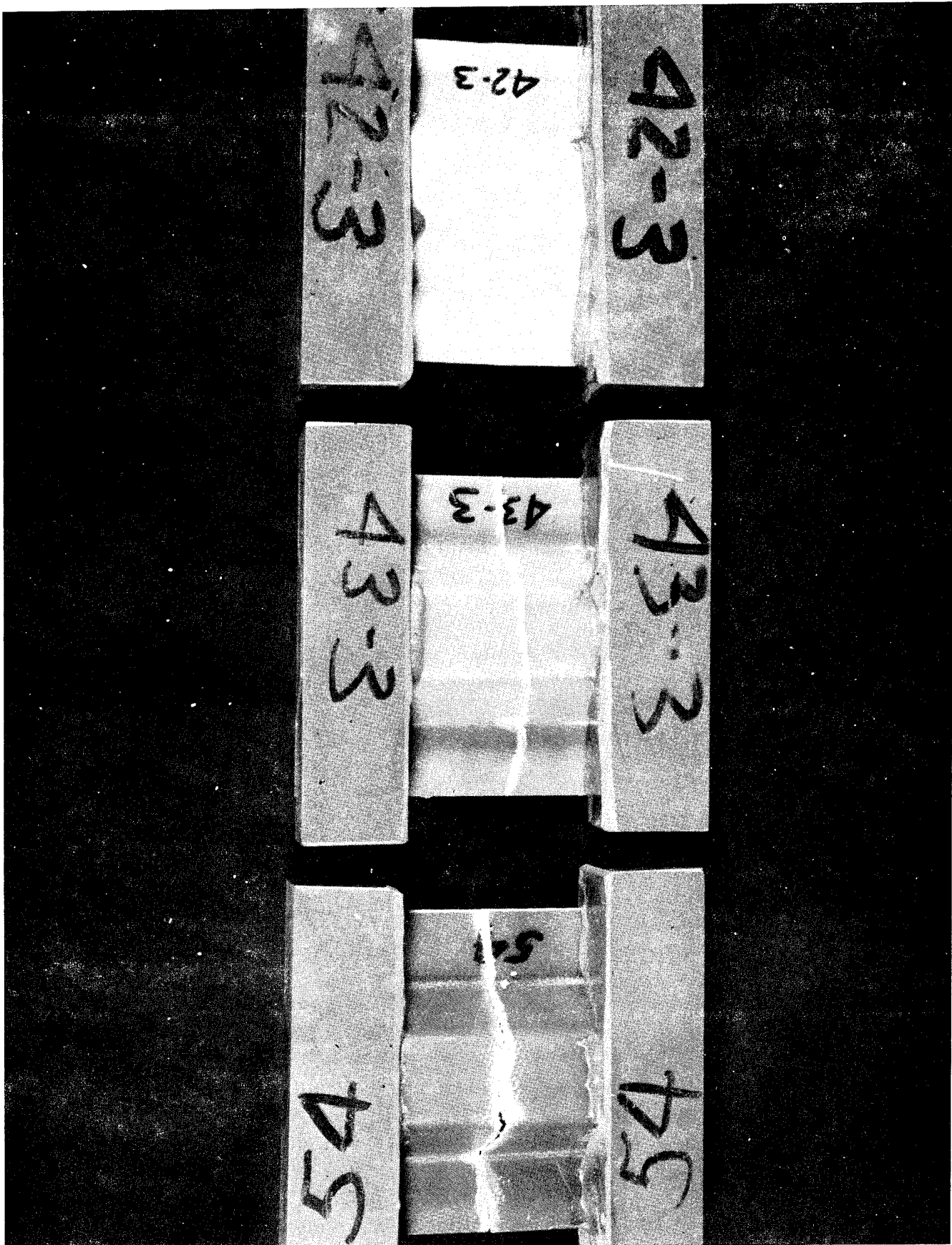
FIGURE 47   181 GLASS FABRIC CORRUGATED PANELS AFTER COMPRESSION TESTING
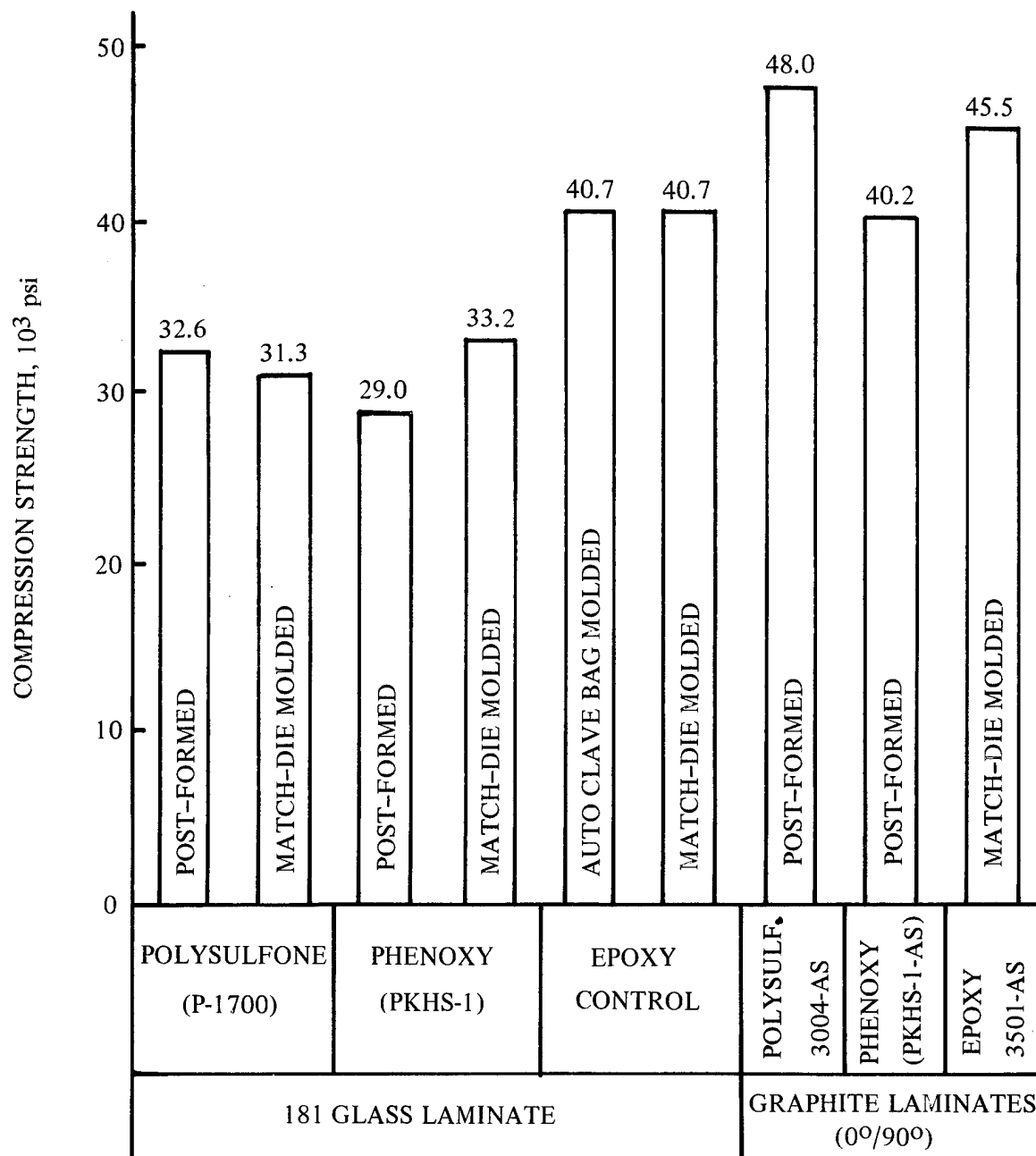
FIGURE 48 COMPRESSION STRENGTH OF CORRUGATED COMPOSITE PANELS
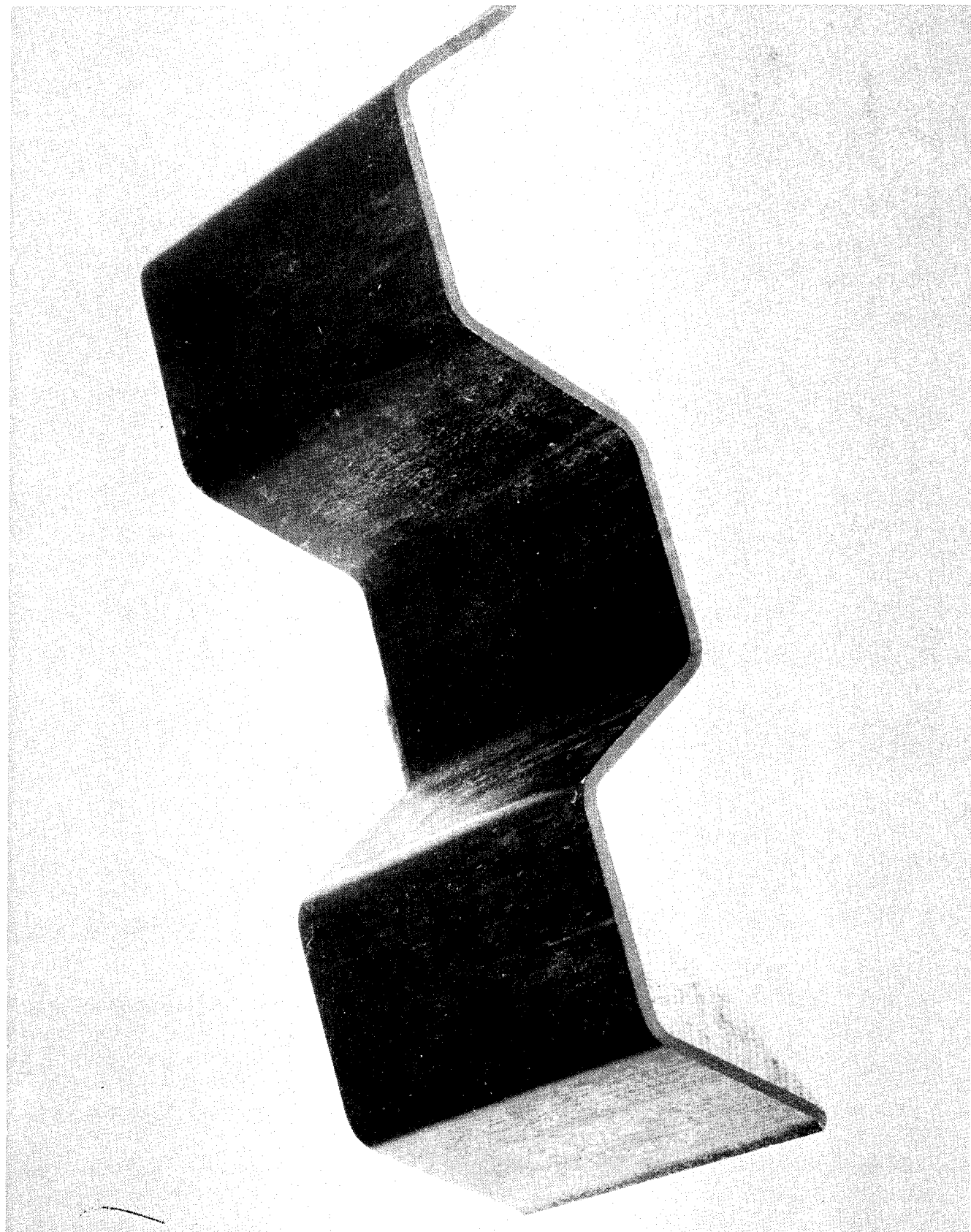
FIGURE 49   POST-FORMED 3004-AS GRAPHITE CORRUGATED PANEL – 0°/90° ORIENTATION
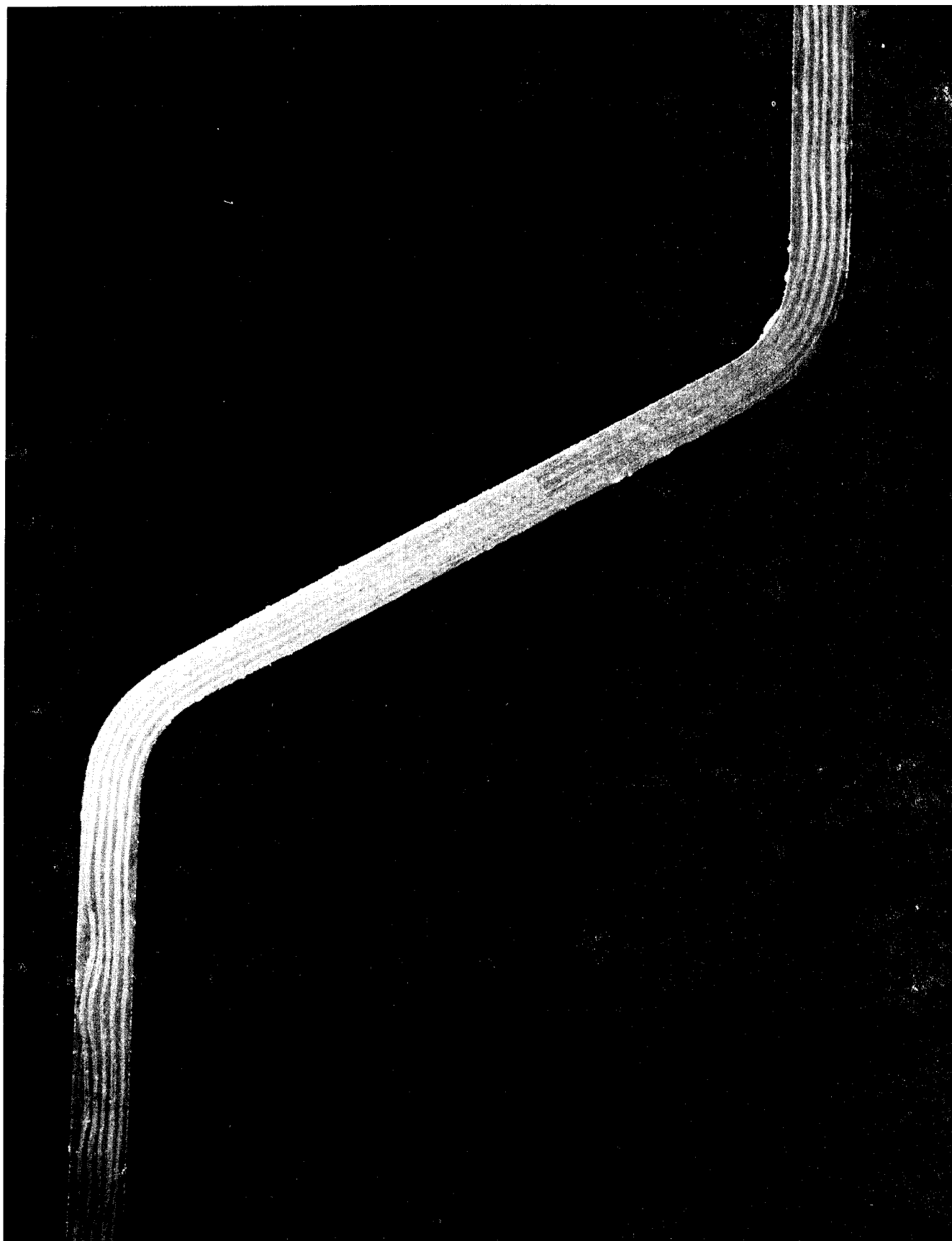
FIGURE 50   ENLARGEMENT OF A 3004-AS POST-FORMED CORRUGATED PANEL

83
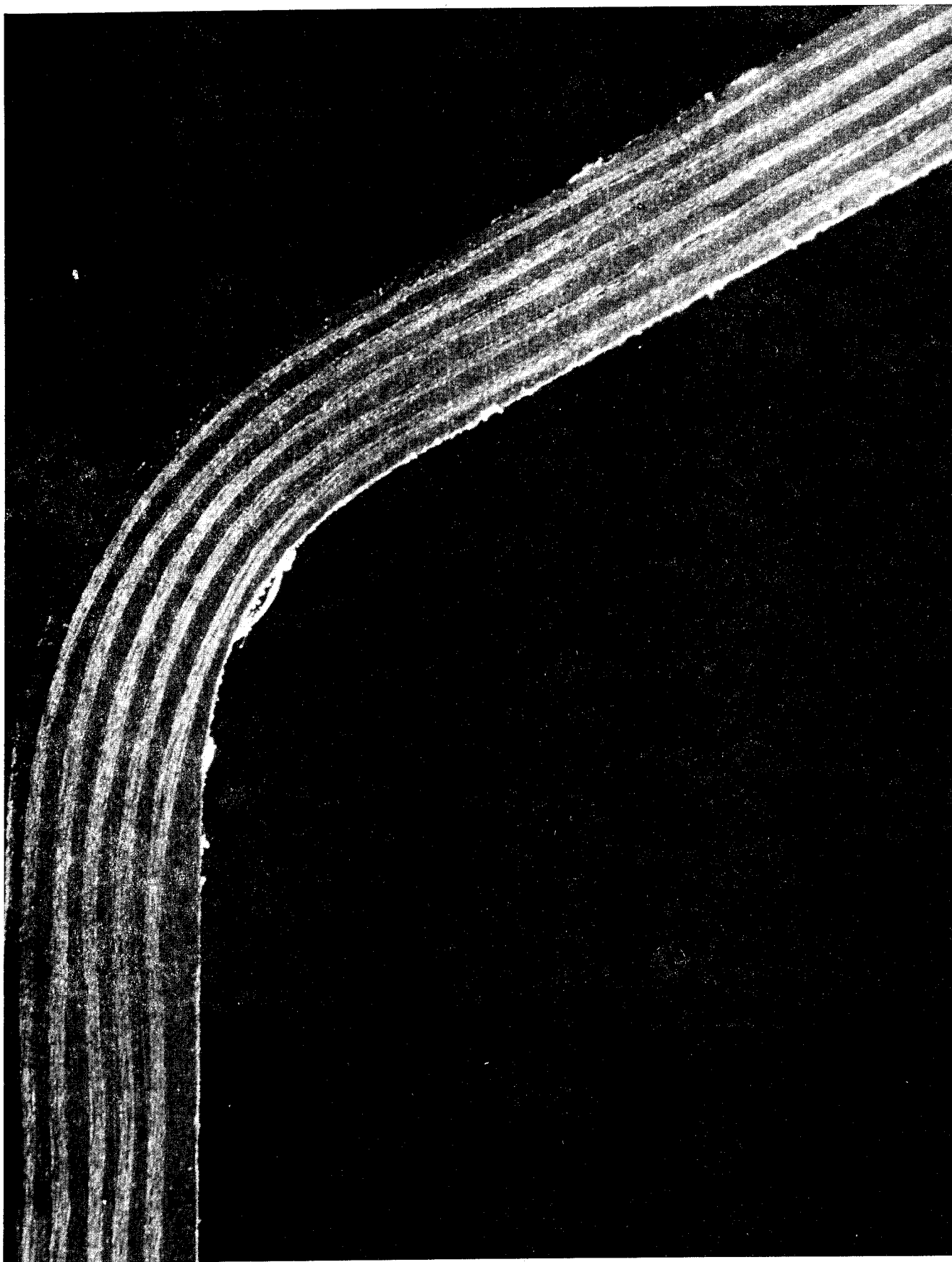
FIGURE 51   ENLARGEMENT OF CORNER RADII OF A 3004-AS POST-FORMED
CORRUGATED PANEL

X3501/A-S graphite epoxy corrugated panel which was fabricated and tested for comparison. The thermoplastic and thermoset panels, which appear to have similar structural quality, are shown in Figure 52 after test.

In summary, the manufacturing studies demonstrated that structural shapes could be post-formed from standard sheet stock without degrading the quality of the laminate and that the resulting quality was equal to that obtained with the thermosetting type resins.

2.3.3   COST ASSESSMENTS

Manufacturing cost studies were performed on three different composite components to assess whether or not reinforced thermoplastic components could indeed offer potential cost savings. The first component studied was a fairing for the Boeing 737 commercial jetliner. The fairing, shown in Figure 53, is approximately 14" long and 16" wide. The skins are 181 style glass fabric. One skin is 4-plys and the other 3-plys thick, with both skins having localized doublers. They are bonded to a tapered 3/8" cell HRP fiberglass core. The part has a complex contour, as illustrated.

The second part used for the study was a 7-ply curved access panel with local doublers as shown in Figure 54. The dimensions of the panels were 24" x 24".

The third component was a simple 7-ply corrugated panel shown in Figure 44 with no doublers or attachments. This component represents costs associated with fabricating simple z-sections, hat stiffeners or flat panels.

Figure 55 shows three possible approaches to component fabrication with thermoplastic materials. Method I involves purchasing prepreg tape or fabric and laying-up the component using the same techniques and procedures currently being used with thermosetting prepreg. In Method II the material is purchased in plied and oriented sheet form, but not laminated. Finally, the most attractive method, shown in Method III, is where laminate pre-oriented sheet stock is purchased and post-formed into components.

Table II shows the manufacturing time associated with the fabrication of each component using each of the three manufacturing concepts and compares these to conventional epoxy glass fabric lay-up techniques. All costs are based on a production run of at least 100 articles.

85
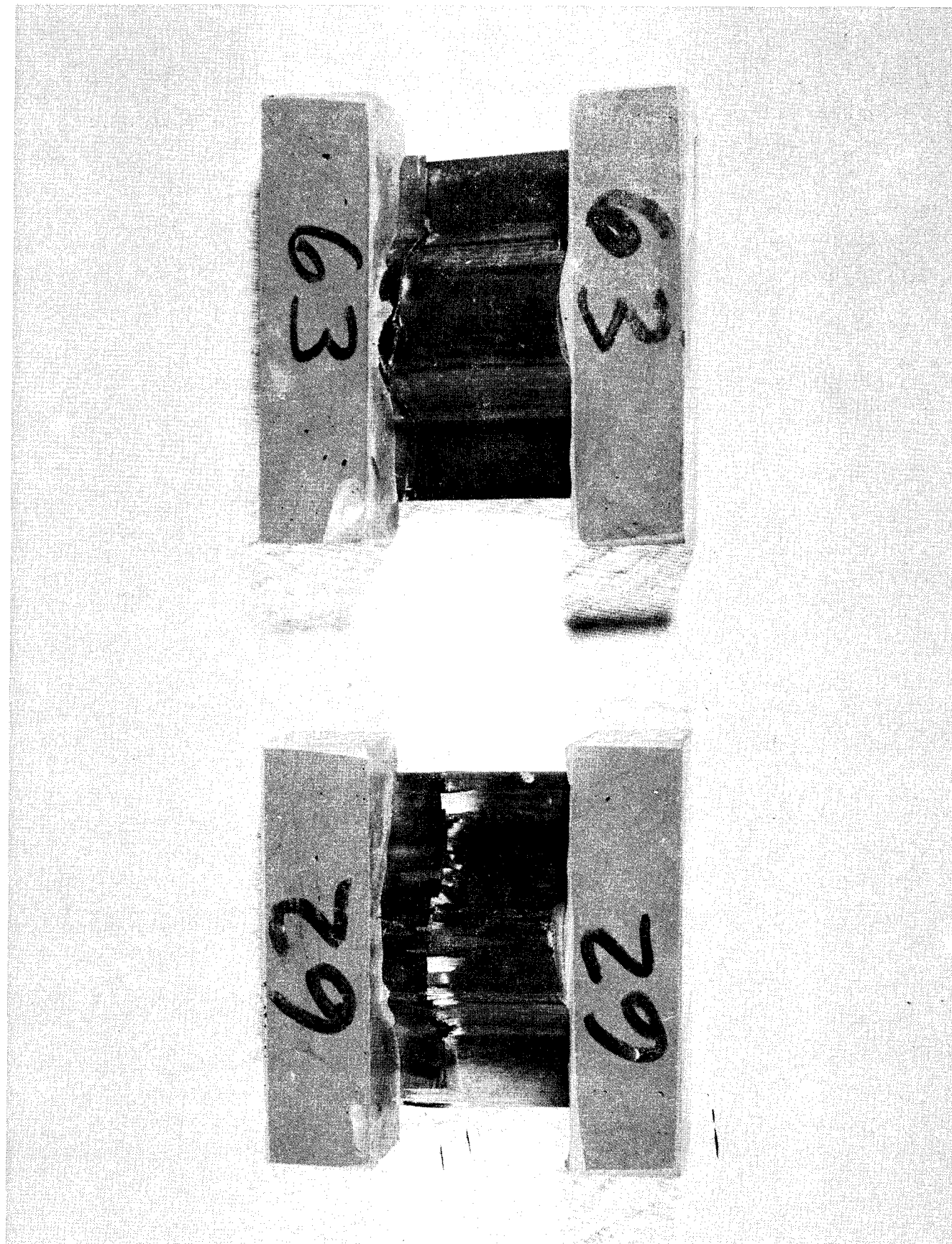
FIGURE 52   GRAPHITE REINFORCED CORRUGATED PANELS AFTER COMPRESSION TESTING
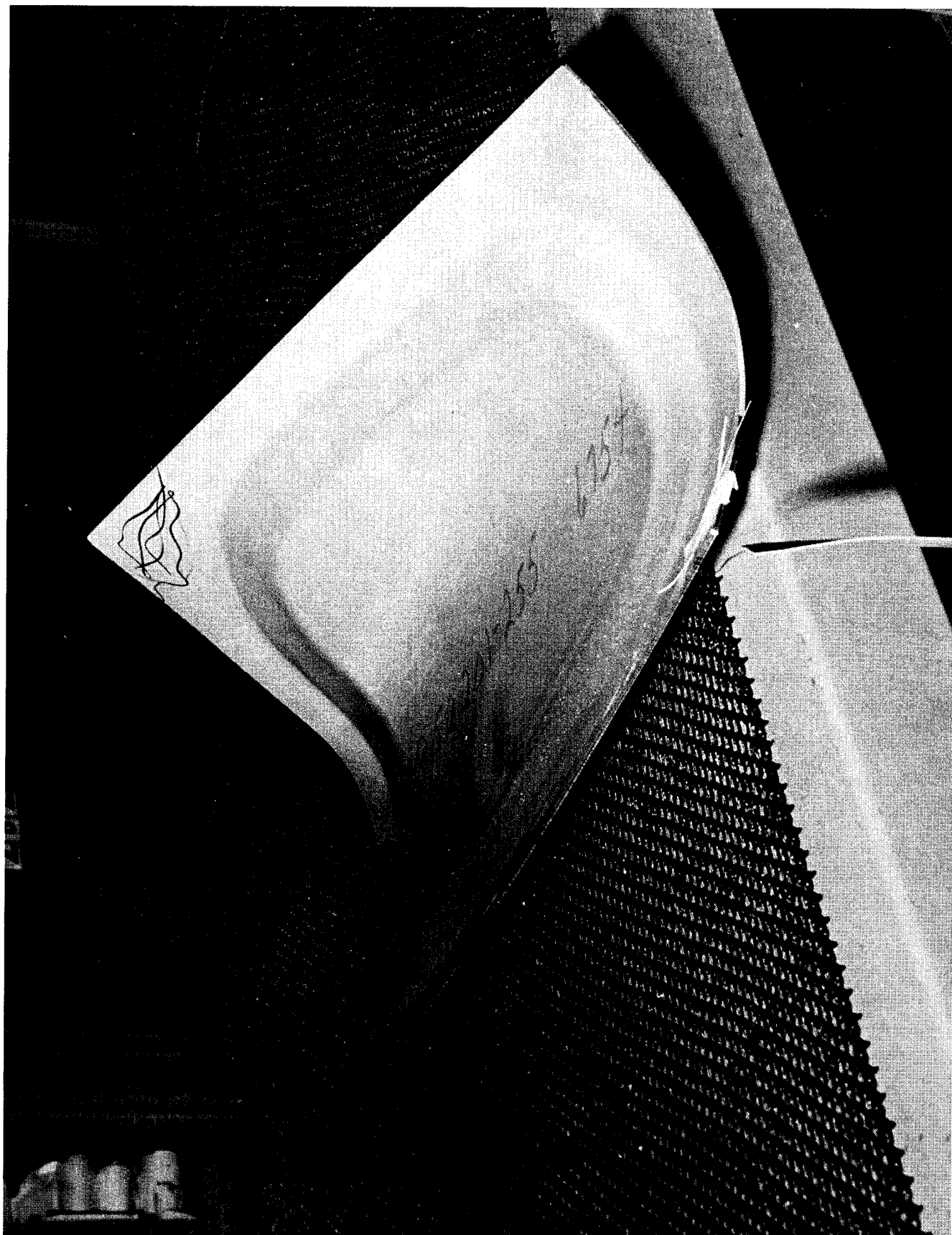
FIGURE 53   FIBERGLASS FAIRING FOR BOEING 737 AIRPLANE
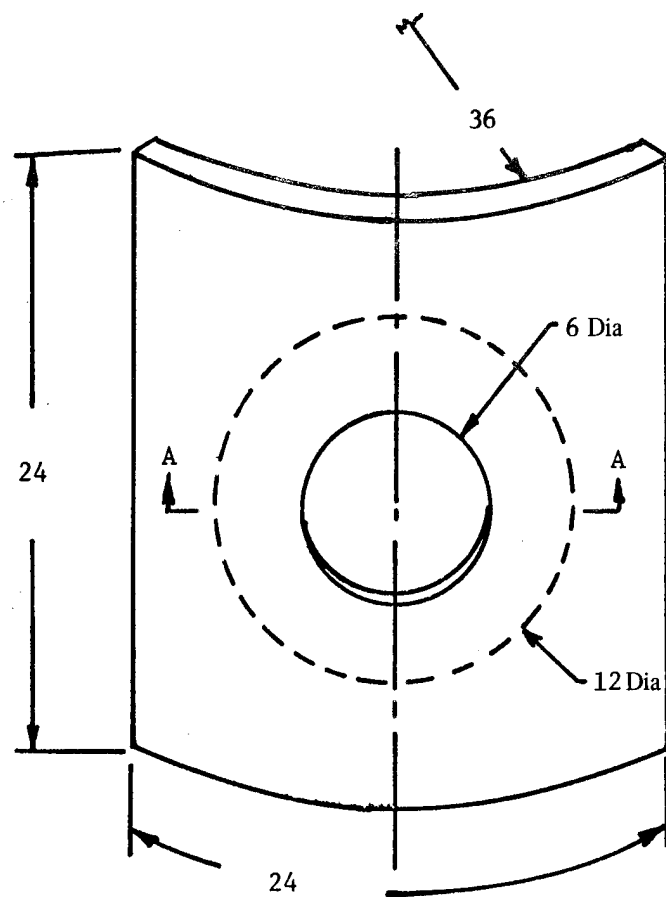
1 ▷   **7**-Ply   (0, +45, −45, 90, −45, +45, 0)

2 ▷   8 Ply   (0, 90, +45, −45, −45, +45, 90, 0)
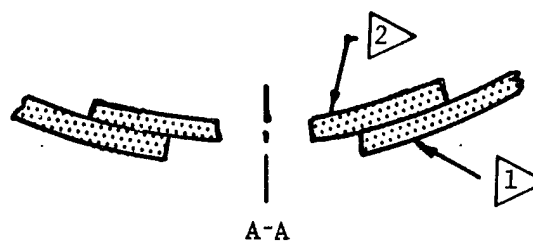
FIGURE 54   TYPICAL ACCESS PANEL
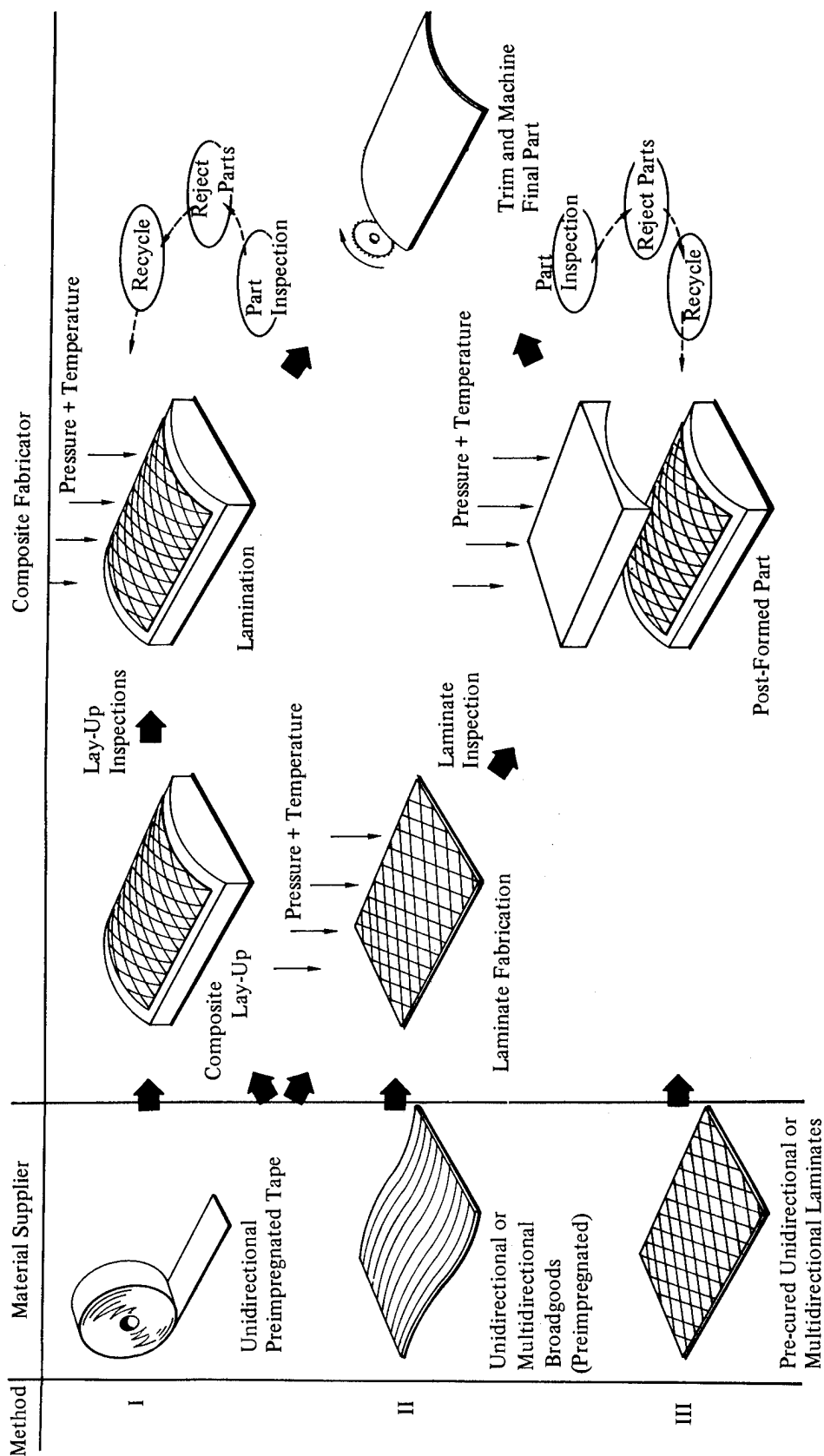
FIGURE 55 : FABRICATION CONCEPTS FOR REINFORCED THERMOPLASTIC COMPOSITES

89

TABLE II FABRICATION COST ASSESSMENT

Fabrication Method ▷2		Fabrication Costs ▷1 — Manhours			
		Honeycomb Fairing (Autoclave)	Curved Access Panel (Autoclave)	Stiffener (Autoclave)	Stiffener (Press Molded)
Conventional Epoxy	Cost	22	14	10	8.5
Method I	Cost	22	13	7	5.5
	Savings — %	(0)	(7)	(30)	(35)
Method II	Cost	17	9	6.5	5.0
	Savings — %	(22)	(36)	(35)	(41)
Method III	Cost	15	5	4	2.5
	Savings — %	(32)	(64)	(60)	(70)

▷1 Cost per part based on a production run of 100 parts minimum. Does not include savings resulting from lower scrappage rate. Does not include tooling costs.

▷2 Refer to Figure 55

2.3.3 (Continued)

As one would expect, Method I results in little cost savings over standard process techniques, since the only manufacturing step minimized is the curing time. In fact, the lay-up time is slightly increased with the thermoplastic materials due to their lack of tack and increased stiffness of the prepreg. Method II results in moderate but significant cost savings, since the lay-up time of the skin and doublers is reduced in addition to the cure time. The most drastic savings result when Method III is utilized. Using this process, the skins are post-formed and the doublers are applied and bonded in one operation. The thermoplastic resins readily adhere to one another during the forming process eliminating the need for an additional ahdesive. With this latter method, the manufacturing cost savings ranged from 32 % for the fairing to over 70% for the corrugated panel. The cost savings on the fairing component was lower since much of the production costs are associated with machining, cleaning and forming the HRP core.

Added manufacturing cost savings can be acheived with the thermoplastic concept through a lower scrappage rate. The scrappage rate of the 737 composite honeycomb fairing discussed above, is approximately 5%. Since the thermoplastics can be recycled (reprocessed) if they are defective, it is estimated, from the type of rejections that do occur, that the scrappage rate can be reduced to less than 1%. An added advantage is that the thermoplastics in either the prepreg or laminate form have an indefinite shelf life at +70° F, eliminating the loss of over-aged material and the need for special storage facilities.

Due to the scope of this program, a complete and comprehensive study of manu-facturing cost savings could not be performed. But based on the parts analyzed and the acutal manufacturing costs associated with their fabrication, definite cost savings can be realized. The cost savings should be obtained with graphite fiber reinforced composites.

3.0 CONCLUSIONS AND RECOMMENDATIONS

The principal objective of this program was to demonstrate the feasibility of fabricating structural reinforced thermoplastic laminates, and this objective was met. Glass fabric laminates were prepared from polysulfone and phenoxy thermoplastic resins which exhibit mechanical properties, environmental resistance and electrical characteristics equivalent to structural epoxy fiberglass laminates.

Based on the studies conducted, polysulfone (P-1700) was the best material of the two thermoplastic resins evaluated. It has service capabilities of +300° F and in select applications, to +350° F. The polysulfone met or exceeded the properties of Narmco 551 epoxy laminate material in tension, compression and flexural properties over a temperature range of -65° F to +350° F. It was slightly lower in interlaminar shear strength over the same temperature range. Similar results were achieved with the phenoxy system within the temperature range of -65° F to +180° F. From the test results, the phenoxy has an upper service temperature of approximately +165° F. Both thermoplastic matrices had excellent creep and fatigue characteristics within their service temperature range. Impact strengths are improved 20-30% over epoxy laminate materials.

The environmental resistance of the reinforcement thermoplastic laminates was equivalent to the epoxy controls. The materials were evaluated for thermal aging, salt-water exposure, weathering, water-boil, flammability and fluid resistance. These studies produced no information that would preclude their use in aircraft structure.

The limited information obtained on graphite reinforced thermoplastic indicates that the thermoplastic polymers are compatible with the graphite fibers. The mechanical properties of the graphite composites appear satisfactory for structural usage with the thermoplastic matrix offering significant improvements in impact strength (50%) and thermal shock (resin crazing) characteristics. Based on these limited studies, additional property investigation is recommended for graphite reinforced thermoplastic composites. Items of specific interest are strength retention at elevated temperature after prolonged room temperature aging, fracture modes, creep and fatigue characteristics.

3.0   (Continued)

The thermoplastic composites can be thermally post-formed into complex contours
and shapes without degrading the laminate quality. This applies to both glass and
graphite reinforced composites. Using the post-formed concept, manufacturing cost
can be reduced as much as 50-70% for some composite components.

In summary, reinforced thermoplastic laminates can reduce the manufacturing
cost of composite structure with little or no sacrifice in structural performance.
Based on these studies and the benefits shown, more extensive investigations into
these materials are warranted. In addition, other polymers within the thermoplastic
field should be reviewed for applicability since there are many polymers with
drastically different properties and processing behavior which may be better suited
for selected applications.

4.0　REFERENCES

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APPENDIX

TABLE A-1   EFFECTS OF THERMAL AGING ON 181 GLASS FABRIC LAMINATES

MATERIAL	PANEL NO.	SPEC NO.	EXPOSURE TEMP.	EXPOSURE TIME	SPEC THICK. INCH	SPEC WIDTH. INCH	SPECIMEN WEIGHT, gms INITIAL	FINAL	NET CHG	% CHG	TEST TEMP.	FLEX STR. 10^3 PSI	FLEX MOD. 10^6 PSI	APPEARANCE
EPOXY	1	1	180°F	10 HR	.0993	.505	6.2407	6.2398	-.0009	N.C. *	RT	73.7	3.33	N.C.
(CONTROL)		2		10	.0995	.506	6.2643	6.2635	-.0008	N.C.		74.6	3.30	
												(74.2)	(3.32)	
		3		100	.0990	.503	6.1898	6.1852	-.0046	-.07		73.0	3.37	
		4		100	.0991	.500	6.1804	6.1758	-.0046	-.07		73.8	3.30	
												(77.7)	(3.34)	
		5		1000	.1010	.508	6.3635	6.3570	-.0066	-.10		76.4	3.22	
		6		1000	.1004	.509	6.3589	6.3526	-.0063	-.10		78.9	3.20	
												(77.7)	(3.21)	
		7	350°F	10	.1001	.502	6.2588	6.2440	-.0148	-.24		74.3	3.35	LT BROWN
		8		10	.1009	.503	6.3077	6.2932	-.0145	-.23		72.5	3.26	
												(73.4)	(3.31)	
		9		100	.1006	.509	6.3558	6.3177	-.0381	-.60		74.7	3.43	DARK
		10		100	.1002	.497	6.2123	6.1747	-.0376	-.60		76.8	3.38	BROWN
												(75.8)	(3.41)	
		11		1000	.0992	.506	6.2306	6.0240	-.2066	-3.32		40.0	2.68	BLACK
		12		1000	.1005	.503	6.2892	6.0961	-.1931	-3.07		41.0	2.64	
												(40.5)	(2.66)	

* N.C. = NO CHANGE

4802 5790 ORIG

96

TABLE A-1 EFFECTS OF THERMAL AGING ON 181 GLASS FABRIC LAMINATES (CON'T)

MATERIAL	PANEL NO.	SPEC NO.	EXPOSURE TEMP.	EXPOSURE TIME	SPEC THICK. INCH	SPEC WIDTH. INCH	SPECIMEN WEIGHT, gms INITIAL	FINAL	NET CHG	% CHG	TEST TEMP.	FLEX STR. 10^3 PSI	FLEX MOD. 10^6 PSI	APPEARANCE
PHENOXY (PKHS-1)	32-5	1	180°F	10 HRS	.0775	.515	5.1309	5.1311	+.0002	N.C.	RT	84.1	4.53	N.C.*
		2			.0775	.520	5.1535	5.1538	+.0003	→		81.1	4.49	
		3			.0780	.515	5.1623	5.1628	+.0005			82.6	4.53	
												(82.6)	(4.52)	
		4		100	.0760	.519	5.1288	5.1272	-.0016	-.03		84.1	4.71	N.C.
		5			.0775	.514	5.1159	5.1142	-.0017	-.03		82.1	4.63	→
		6		→	.0774	.514	5.1217	5.1200	-.??7	-.03		83.3	4.56	→
												(83.2)	(4.63)	
		7		1000	.0774	.518	5.1373	5.1347	-.0026	-.05		85.1	4.61	N.C.
		8			.0772	.517	5.1459	5.1433	-.0026	-.05		88.8	4.57	→
		9	→	→	.0762	.517	5.0995	5.0968	-.0?..	-.05	→	86.9	4.69	→
												(86.9)	(4.62)	
POLYSULFONE P-1700	34-4	1	350°F	10	.0744	.518	5.1277	5.1248	-.0029	-.05	RT	75.4	4.13	N.C.
		2			.0731	.517	5.0588	5.0561	-.??..	-.05		82.3	4.71	→
		3		→	.0750	.516	5.1381	5.1351	-.0030	-.05		85.1	4.71	→
												(80.9)	(4.52)	
		4		100	.0750	.513	5.0451	5.0423	-.0028	-.05		83.1	4.65	N.C.
		5			.0741	.506	4.9933	4.9905	-.0028	-.05		84.5	4.69	→
		6		→	.0730	.511	4.9354	4.9326	-.0028	-.05		81.3	4.86	→
												(83.0)	(4.73)	
		7		1000	.0761	.513	5.0984	5.0953	-.0031	-.05		75.0	4.54	SLIGHT YELLOWING
		8			.0730	.511	4.9992	4.9963	-.0029	-.05		81.0	4.79	→
	→	9	→	→	.0727	.512	4.9232	4.9204	-.0028	-.05	→	83.1	4.98	
												(79.7)	(4.77)	

* NC = NO CHANGE

ö1 4802 5790 ORIG 3/7

TABLE A-2 EFFECTS OF ACCELERATED WEATHERING ON 181 GLASS FABRIC LAMINATES

MATERIAL	PANEL NO.	SPEC. NO.	SPEC. DIMEN., IN. THK.	WIDTH	TEST TEMP.	LOAD, lbs.	STRENGTH, 10^3 PSI		MODULUS, 10^6 PSI		APPEAR-ANCE
PHENOXY	32-5	10	.0770	.518	RT	60.5	88.6		4.48		N.C. **
(PKHS-1)		11	.0775	.519		64.0	92.4		4.58		
↓	↓	12	.0768	.521	↓	54.5	79.8		4.69		↓
							AVE.	86.9	AVE.	4.58	
POLYSULFONE	34-4	10	.0730	.508	RT	49.0	81.5		4.54		SURFACE
(P-1700)		11	.0736	.512		53.0	86.0		4.40		YELLOWING
↓	↓	12	.0730	.514	↓	50.0	82.1		4.56		↓
							AVE.	83.2	AVE.	4.50	
EPOXY	1	13	.1001	.493	RT	82.0	74.7		3.25		PENATRATED
(CONTROL)		14	.1002	.507		84.8	75.0		3.07		BROWNING
↓	↓	15	.1003	.498	↓	82.5	74.1		3.28		↓
							AVE.	74.6	AVE.	3.20	

* 200 HRS ACCELERATED WEATHER EXPOSURE PER ASTM D1499;

** N.C. = NO CHANGE

4802 5790 ORIG 3/71

98

TABLE A-3 EFFECTS OF SALT WATER EXPOSURE ON THE FLEXURAL PROPERTIES OF 181 GLASS FABRIC LAMINATES

MATERIAL	PANEL NO.	SPEC. NO.	SPEC. DIMEN., IN. THK.	SPEC. DIMEN., IN. WIDTH	TEST TEMP.	LOAD, lbs.	STRENGTH, 10^3 PSI		MODULUS, 10^6 PSI		
PHENOXY	32-5	13	.0774	.519	RT	55.0	79.6		4.82		
(PKHS-1)		14	.0773	.519		58.2	84.5		4.70		
	↓	15	.0773	.516	↓	57.0	83.2		4.73		
							AVE.	82.4	AVE.	4.75	
POLYSULFONE	34-4	13	.0727	.517	RT	49.5	81.5		4.86		
(P1700)		14	.0746	.518		47.5	74.1		4.61		
	↓	15	.0755	.511	↓	46.8	72.3		4.45		
							AVE.	76.0	AVE.	4.64	
EPOXY	1	16	.1002	.501	RT	81.2	72.6		3.43		
(CONTROL)		17	.0994	.503		81.0	73.3		3.43		
	↓	18	.1000	.497	↓	79.9	72.3		3.40		
							AVE.	72.7	AVE.	3.42	

* 200 HRS. SALT WATER EXPOSURE PER 3117-64; 100% R.H., 98°F, 5% SALT SOLUTION

TABLE A-4   EFFECTS OF SALT WATER EXPOSURE ON THE PHYSICAL PROPERTIES OF 181 GLASS FABRIC LAMINATES

MATERIAL	PANEL NO.	SPEC NO.	WEIGHT AFTER X-HOURS EXPOSURE, gms.					FINAL WT. LOSS gms.	% WT. LOSS	SPECIMEN THICKNESS, INCH			SPECIMEN WIDTH, INCH		
			0 HRS	50 HRS	100 HRS	150 HRS	200 HRS			INITIAL	FINAL	NET CHG	INITIAL	FINAL	NET CHG
PHENOXY (PKHS-1)	32-5	13	5.1536	5.1590	5.1600	5.1604	5.1613	.0077	0.15	.0774	.0774	NC**	.519	.519	NC
→	→	14	5.1192	5.1244	5.1255	5.1258	5.1267	.0075	0.15	.0773	.0774	→	.519	.519	→
		15	5.1387	5.1440	5.1449	5.1453	5.1464	.0075	0.15	.0773	.0774		.516	.516	
POLYSULFONE (P-1700)	34-4	13	5.0900	5.0953	5.0969	5.0973	5.0986	.0086	0.17	.0727	.0729	NC	0.517	0.517	NC
→	→	14	5.1203	5.1252	5.1272	5.1273	5.1286	.0083	0.16	.0746	.0745	→	0.518	0.518	→
		15	5.0823	5.0877	5.0897	5.0900	5.0908	.0085	0.17	.0755	.0757		0.511	0.511	
EPOXY (CONTROL)	1	16	6.2565	6.2679	6.2709	6.2723	6.2746	.0181	0.29	0.1002	.1011	NC	0.501	0.501	NC
→	→	17	6.2195	6.2303	6.2334	6.2346	6.2371	.0176	0.28	.0994	.0990	→	0.503	0.503	→
		18	6.2223	6.2339	6.2369	6.2383	6.2403	.0180	0.29	.1000	.1016		0.497	0.497	

*   SALT WATER EXPOSURE PER ASTM B117-64; 100% R.H., 98°F, 5% SALT SOLUTION

** N.C. = NO CHANGE

TABLE A-5 EFFECT OF EXPOSURE TO BOILING WATER ON 181 GLASS FABRIC LAMINATES

MATERIAL	PANEL NO.	SPEC NO.	EXPOSURE TEMP.	EXPOSURE TIME	SPEC THICK. INCH	SPEC WIDTH INCH	SPECIMEN WEIGHT, gms INITIAL	FINAL	NET CHG	% CHG	TEST TEMP.	FLEX STR. 10³ PSI	FLEX MOD. 10⁶ PSI	APPEARANCE
POLYSULFONE (P-1700)	44	1	CONTROL		.087	.519	NT	NT	NT	NT	60.5	69.3	3.83	NC
		2	→		.087	.520	→	→	→	→	58.0	66.3	3.71	→
		3			.087	.520	→	→	→	→	60.5	69.2	3.71	
												(69.3)	(3.75)	
		4	212°F	72 Hrs.	.088	.520	5.4847	5.4961	+.0114	+ 0.21	35.5	41.1	3.30	NC
		5	→		.089	.486	5.4298	5.4413	+.0115	+ 0.21	34.0	39.7	3.19	→
		6			.088	.521	5.7412	5.7538	+.0126	+ 0.22	35.0	39.6	3.25	
										(0.21)		(40.1)	(3.25)	
PHENOXY (PKHS-1)	51	1	CONTROL		.075	.488	NT	NT	NT	NT	50.0	82.0	4.26	NC
		2	→		.077	.485	→	→	→	→	45.5	71.2	4.27	→
		3			.077	.488	→	→	→	→	49.2	76.5	4.18	
												(76.6)	(4.24)	
		4	212°F	72 Hrs.	.077	.487	4.8223	5.0215	+.1992	+ 4.13	37.0	57.7	5.40	White &
		5	→		.077	.482	4.8036	5.3308	+.5272	+11.0	33.0	52.2	5.95	Warped
		6			.075	.485	4.7583	5.4346	+.6763	+14.2	33.7	55.6	5.91	
										(9.8)		(55.1)	(5.75)	
EPOXY (CONTROL)	1	1	CONTROL		.100	.513	NT	NT	NT	NT	81.0	71.1	3.21	NC
		2	→		.100	.513	→	→	→	→	81.5	71.5	3.13	→
		3			.100	.517	→	→	→	→	82.0	71.4	3.23	
												(71.3)	(3.18)	
		4	212°F	72 Hrs.	.100	.510	6.1618	6.3315	+.1697	+ 2.56	61.4	54.2	3.03	NC
		5	→		.101	.508	6.2658	6.4491	+.1833	+ 2.93	63.6	55.2	3.10	→
		6			.099	.513	6.3312	6.5172	+.1860	+ 2.94	60.4	54.1	3.28	
										(2.81)		(54.5)	(3.14)	

*TESTED AT 70°F

NC = NO CHANGE
NT = NOT TESTED

4802 5790 ORIG

TABLE A-6 EFFECTS OF FLUID EXPOSURE ON THE FLEXURAL STRENGTH PROPERTIES OF POLYSULFONE/181 GLASS FABRIC LAMINATES

MATERIAL	PANEL NO.	SPEC NO.	EXPOSURE FLUID	TIME	TEMP	SPEC. DIMEN., IN. THK.	WIDTH	FLEX. STR. 10^3 PSI STRESS	% CHG	FLEX. MOD. 10^6 PSI MOD.	% CHG	
POLYSULFONE	34-4	16	MIL-H-	7 DAYS	70°F	.0746	.501	81.5		4.64		
		17	5606	7	70	.0750	.515	77.7		4.78		
								(79.6)	+0.38	(4.71)	+13.0	
		18		28	70	.0739	.515	72.8		4.77		
		19		28	70	.0720	.515	80.9		4.88		
								(76.9)	-3.03	(4.83)	+14.5	
		20		1	160	.0722	.505	80.3		4.87		
		21		1	160	.0749	.513	76.9		4.76		
								(78.9)	-0.50	(4.82)	+14.2	
		22		7	160	.0718	.515	80.0		4.92		
		23		7	160	.0720	.515	80.9		5.02		
								(80.5)	+1.51	(4.97)	+17.8	
		24	MIL-L-	7	70	.0711	.519	75.5		4.88		
		25	7807	7	70	.0718	.511	74.3		4.75		
								(74.9)	-5.55	(4.82)	+14.2	
		26		28	70	.0740	.516	75.6		4.68		
		27		28	70	.0736	.516	76.1		4.69		
								(75.9)	-4.29	(4.69)	+11.1	
		28		1	160	.0757	.517	72.1		4.42		
		29		1	160	.0749	.517	69.8		4.47		
								(71.0)	-10.47	(4.45)	+16.6	
		30		7	160	.0746	.513	70.1		4.60		
		31		7	160	.0734	.508	78.8		4.70		
								(74.5)	-6.05	(4.65)	+10.2	
		32	JP-4	7	70	.0735	.516	75.5		4.87		
		33		7	70	.0749	.517	80.5		4.63		
								(79.0)	-0.38	(4.75)	+12.6	
		34		28	70	.0729	.514	81.5		4.92		
		35		28	70	.0749	.517	80.1		5.09		
								(80.8)	+1.89	(5.01)	+18.7	
		36		1	160	.0744	.516	81.9		4.73		
		37		1	160	.0741	.512	75.4		4.92		
								(78.7)	-0.76	(4.83)	+14.5	
		38		7	160	.0741	.516	81.0		4.73		
		39		7	160	.0748	.508	73.6		4.73		
								(77.3)	-2.52	(4.73)	+12.1	

* UNEXPOSED STR. = 79.3 x 10^3 PSI AND MOD. = 4.22 x 10^6 PSI

TABLE A-7 EFFECTS OF FLUID EXPOSURE ON THE PHYSICAL PROPERTIES OF POLYSULFONE/181 GLASS FABRIC LAMINATES

MATERIAL	PANEL NO.	SPEC. NO.	EXPOSURE FLUID	EXPOSURE TIME	EXPOSURE TEMP.	SPECIMEN THICKNESS, INCH INITIAL	FINAL	NET CHG	% CHG	SPECIMEN WIDTH, INCH INITIAL	FINAL	NET CHG	% CHG	SPECIMEN WEIGHT, gms INITIAL	FINAL	NET CHG	% CHG	APPEARANCE
POLYSULFONE (P-1700)	34-4	16	MIL-H-5606	7 DAYS	70°F	.0746	.0747	N.C.	N.C.	.501	.501	N.C.	N.C.	4.9764	4.9823	.0059	.12	N.C.*
		17	5606	7	70	.0750	.0750			.515	.515			5.1374	5.1437	.0063	.12	
		18		28	70	.0739	.0740			.515	.515			5.1159	5.1242	.0083	.16	
		19		28	70	.0720	.0720			.515	.517			5.0452	5.0536	.0084	.16	
		20		1	160	.0722	.0723			.505	.505			4.9164	4.9242	.0078	.16	
		21		1	160	.0749	.0750			.513	.51?			5.0870	5.0913	.0043	.08	
		22		7	160	.0718	.0714			.515	.515			5.0047	5.0204	.0157	.31	
		23		7	160	.0720	.0720			.515	.515			5.0390	5.0449	.0059	.12	
		24	MIL-L-7807	7	70	.0711	.0712	N.C.	N.C.	.519	.519	N.C.	N.C.	5.0345	5.0471	.0126	.25	N.C.
		25		7	70	.0718	.0720			.511	.511			4.9971	5.0107	.0136	.27	
		26		28	70	.0740	.0742			.516	.517			5.1158	5.1328	.0170	.33	
		27		28	70	.0736	.0735			.516	.516			5.0645	5.0795	.0150	.30	
		28		1	160	.0757	.0758			.517	.517			5.1554	5.1663	.0109	.21	
		29		1	160	.0749	.0748			.517	.517			5.1121	5.1225	.0104	.20	
		30		7	160	.0746	.0748			.513	.513			5.0580	5.0701	.0121	.24	
		31		7	160	.0734	.0735			.508	.508			5.0062	5.0182	.0120	.24	
		32	JP-4	7	70	.0735	.0739	N.C.	N.C.	.516	.516	N.C.	N.C.	5.0860	5.1025	.0165	.32	N.C.
		33		7	70	.0749	.074?			.517	.517			5.1391	5.1555	.0164	.32	
		34		28	70	.0729	.0729			.514	.515			4.9701	4.9915	.0214	.43	
		35		28	70	.0716	.0715			.517	.517			5.0335	5.0551	.0216	.43	
		36		1	160	.0762	.0770			.518	.518			5.1355	5.1381	.0026	.05	
		37		1	160	.0774	.0774			.520	.520			5.1790	5.1816	.0026	.05	
		38		7	160	.0767	.0768			.517	.517			5.1037	5.1060	.0023	.05	
		39		7	160	.0786	.0785			.516	.516			5.1664	5.1685	.0023	.04	

* N.C. = NO CHANGE

C-1 4402 5790 ORIG 3/71

TABLE A-8 EFFECTS OF FLUID EXPOSURE ON FLEXURAL PROPERTIES OF PHENOXY/181 GLASS FABRIC LAMINATES

MATERIAL	PANEL NO.	SPEC NO.	EXPOSURE			SPEC. DIMEN., IN.		FLEX. STR. 10^3 PSI		FLEX. MOD. 10^6 PSI		
			FLUID	TIME	TEMP	THK.	WIDTH	STRESS	% CHG	MOD.	% CHG	
PHENOXY	32-5	16	MIL-H-	7 DAYS	70°F	.0794	.517	84.2		4.56		
(PKHS-1)		17	5606	7	70	.0763	.498	79.2		4.76		
								(81.7)	+5.15	(4.66)	+10.7	
		18		28	70	.0757	.518	85.2		4.69		
		19		28	70	.0774	.499	82.8		4.55		
								(84.0)	+8.11	(4.62)	+ 9.7	
		20		1	160	.0778	.517	76.2		4.63		
		21		1	160	.0766	.518	77.7		4.67		
								(77.0)	-0.90	(4.65)	+10.5	
		22		7	160	.0768	.514	75.1		4.67		
		23		7	160	.0775	.518	85.3		4.59		
								(80.2)	+3.22	(4.63)	+10.0	
		24	MIL-L	7	70	.0763	.519	74.5		4.57		
		25	7807	7	70	.0774	.520	80.2		4.37		
								(77.4)	-0.39	(4.47)	+ 6.2	
		26		28	70	.0760	.519	69.1		4.30		
		27		28	70	.0774	.519	77.4		4.12		
								(73.2)	-5.79	(4.21)	N.C. **	
		28		1	160	.0775	.517	80.0		4.46		
		29		1	160	.0773	.516	75.9		4.56		
								(78.0)	+0.39	(4.51)	+ 7.1	
		30		7	160	.0760	.520	85.4		4.61		
		31		7	160	.0780	.515	76.8		4.53		
								(81.1)	+4.38	(4.57)	+ 8.6	
		32	JP-4	7	70	.0770	.519	79.4		4.59		
		33		7	70	.0761	.515	78.5		4.64		
								(79.0)	+1.67	(4.62)	+ 9.7	
		34		28	70	.0782	.514	80.9		4.59		
		35		28	70	.0761	.514	78.6		4.65		
								(79.8)	+2.70	(4.62)	+ 9.7	
		36		1	160°F	.0769	.518	85.9		4.61		
		37		1	160	.0774	.520	80.9		4.51		
								(83.4)	+7.34	(4.56)	+ 8.3	
		38		7	160	.0767	.517	81.4		4.66		
		39		7	160	.0786	.516	86.4		4.50		
								(83.9)	+7.98	(4.58)	+ 8.8	

* UNEXPOSED STR. = 77.7 x 10^3 PSI, MOD. = 4.21 x 10^6 PSI   **NC = NO CHANGE

TABLE A-9 EFFECTS OF FLUID EXPOSURE ON THE PHYSICAL PROPERTIES OF PHENOXY/181 GLASS FABRIC LAMINATES

MATERIAL	PANEL NO.	SPEC. NO.	EXPOSURE FLUID	EXPOSURE TIME	EXPOSURE TEMP.	SPECIMEN THICKNESS, INCH INITIAL	FINAL	NET CHG	% CHG	SPECIMEN WIDTH, INCH INITIAL	FINAL	NET CHG	% CHG	SPECIMEN WEIGHT, gms INITIAL	FINAL	NET CHG	% CHG	APPEARANCE
PHENOXY (PKHS-1)	32-5	16	MIL-H-5606	7 DAYS	70°F	.0794	.0795	N.C.	N.C.	.517	.517	N.C.	N.C.	5.2055	5.2099	.0044	.08	N.C. *
		17		7	70	.0763	.0763			.498	.498			4.9399	4.9440	.0041	.08	
		18		28	70	.0757	.0758			.518	.518			5.1032	5.1058	.0026	.05	
		19		28	70	.0774	.0771			.499	.501			5.0017	5.0045	.0028	.06	
		20		1	160	.0778	.0778			.517	.517			5.1422	5.1460	.0038	.07	
		21		1	160	.0766	.0765			.518	.518			5.1135	5.1165	.0030	.06	
		22		7	160	.0768	.0767			.514	.514			5.0953	5.0965	.0012	.02	
		23		7	160	.0775	.0774			.518	.519			5.1525	5.1534	.009	.02	
		24	MIL-L-7807	7	70	.0763	.0763	N.C.	N.C.	.519	.519	N.C.	N.C.	5.1313	5.1362	.0049	.09	N.C.
		25		7	70	.0774	.0775			.520	.520			5.1641	5.1692	.0051	.09	
		26		28	70	.0760	.0760			.519	.519			5.1158	5.1236	.0078	.15	
		27		28	70	.0774	.0774			.519	.519			5.1769	5.1831	.0062	.12	
		28		1	160	.0775	.0774			.517	.517			5.1581	5.1605	.0024	.05	
		29		1	160	.0773	.0774			.516	.516			5.1342	5.1364	.0022	.05	
		30		7	160	.0760	.0760			.520	.520			5.1208	5.1222	.0014	.03	
		31		7	160	.0780	.0781			.515	.515			5.1682	5.1697	.0015	.03	
		32	JP-4	7	70	.0770	.0770	N.C.	N.C.	.519	.519	N.C.	N.C.	5.1483	5.1498	.0015	.03	N.C.
		33		7	70	.0761	.0760			.515	.515			5.0368	5.0690	.0022	.04	
		34		28	70	.0782	.0784			.514	.515			5.1440	5.1464	.0024	.05	
		35		28	70	.0761	.0761			.514	.514			5.0785	5.0809	.0024	.04	
		36		1	160	.0769	.0770			.518	.518			5.1355	5.1381	.0026	.05	
		37		1	160	.0774	.0774			.520	.520			5.1790	5.1816	.0026	.05	
		38		7	160	.0767	.0768			.517	.517			5.1037	5.1060	.0023	.05	
		39		7	160	.0786	.0785			.516	.516			5.1664	5.1685	.0023	.04	

* N.C. = NO CHANGE

D1 4802 5790 ORIG 3/71

TABLE A-10 EFFECTS OF FLUID EXPOSURE ON FLEXURAL PROPERTIES OF EPOXY/181 GLASS FABRIC LAMINATES

MATERIAL	PANEL NO.	SPEC NO.	EXPOSURE FLUID	TIME	TEMP	SPEC. DIMEN., IN. THK.	WIDTH	FLEX. STR. 10^3 PSI STRESS	% CHG*	FLEX. MOD. 10^6 PSI MOD.	% CHG*	
EPOXY	1	19	MIL-H-	7 DAYS	70°F	.0983	.501	74.4		3.38		
(CONTROL)		20	5606	7	70	.0997	.504	73.7		3.30		
								(74.1)	+3.93	(3.34)	+ 5.03	
		21		28	70	.1006	.485	73.1		3.25		
		22		28	70	.0980	.505	71.4		3.44		
								(72.3)	+1.40	(3.35)	+ 5.35	
		23		1	160	.1001	.499	70.7		3.21		
		24		1	160	.0993	.504	77.0		3.42		
								(73.9)	+3.65	(3.82)	+20.13	
		25		7	160	.0982	.500	75.2		3.56		
		26		7	160	.1000	.505	74.0		3.34		
								(74.6)	+4.63	(3.45)	+ 8.49	
		27	MIL-L-	7	70	.0997	.504	76.5		3.38		
		28	7807	7	70	.1011	.506	73.5		3.28		
								(75.0)	+5.19	(3.32)	+ 4.40	
		29		28	70	.0997	.504	72.8		3.46		
		30		28	70	.1008	.498	72.7		3.31		
								(72.8)	+2.10	(3.39)	+ 6.60	
		31		1	160	.0990	.505	76.8		3.36		
		32		1	160	.0988	.503	77.0		3.40		
								(76.9)	+7.85	(3.38)	+ 6.29	
		33		7	160	.0981	.504	76.1		3.46		
		34		7	160	.1002	.506	74.4		3.32		
								(75.3)	+5.61	(3.39)	+ 6.60	
		35	JP-4	7	70	.0986	.503	71.2		3.40		
		36		7	70	.0990	.503	74.8		3.32		
								(73.0)	+2.38	(3.36)	+ 5.66	
		37		28	70	.0988	.499	73.9		3.42		
		38		28	70	.1005	.505	72.3		3.24		
								(73.1)	+2.52	(3.33)	+ 4.72	
		39		1	160	.1000	.517	72.2		3.39		
		40		1	160	.1005	.520	71.3		3.20		
								(71.8)	+0.70	(3.30)	+ 3.77	
		41		7	160	.0995	.507	74.0		3.30		
		42		7	160	.0993	.522	71.6		3.34		
								(72.8)	+2.10	(3.32)	+ 4.40	

* UNEXPOSED, STR. = 71.3 x 10^3 PSI, MOD. = 3.18 x 10^6 PSI

106

TABLE A-11 EFFECTS OF FLUID EXPOSURE ON THE PHYSICAL PROPERTIES OF EPOXY/181 GLASS FABRIC LAMINATES

MATERIAL	PANEL NO.	SPEC. NO.	EXPOSURE FLUID	EXPOSURE TIME	EXPOSURE TEMP.	SPECIMEN THICKNESS, INCH INITIAL	FINAL	NET CHG	% CHG	SPECIMEN WIDTH, INCH INITIAL	FINAL	NET CHG	% CHG	SPECIMEN WEIGHT, gms INITIAL	FINAL	NET CHG	% CHG	APPEARANCE
EPOXY (CONTROL)	1	19	MIL-H-5606	7 DAYS	70°F	.0983	.0977	-.0006	-0.61	.501	.501	N.C.	N.C.	6.1789	6.1854	.0065	.11	N.C. *
		20	5606	7	70	.0997	.1000	N.C.	N.C.	.504	.504			6.2585	6.2651	.0066	.11	
		21		28	70	.1006	.1009	N.C.	N.C.	.485	.485			6.0749	6.0803	.0054	.09	
		22		28	70	.0980	.0984	N.C.	N.C.	.505	.505			6.2193	6.2246	.0053	.08	
		23		1	160	.1001	.1000	N.C.	N.C.	.499	.499			6.2500	6.2553	.0053	.08	
		24		1	160	.0993	.0988	N.C.	N.C.	.504	.503			6.2574	6.2610	.0036	.06	
		25		7	160	.0982	.0982	N.C.	N.C.	.500	.500			6.1800	6.1813	.0013	.02	
		26		7	160	.1000	.1017	+.0017	+1.70	.505	.505			6.2214	6.2902	.0012	-.02	
		27	MIL-L-7807	7	70	.0997	.1001	N.C.	N.C.	.504	.504	N.C.	N.C.	6.2294	6.3054	.0060	.10	N.C.
		28	7807	7	70	.1011	.1012	N.C.	N.C.	.506	.505			6.3465	6.3543	.0078	.12	
		29		28	70	.0997	.0993	N.C.	N.C.	.504	.504			6.2285	6.2319	.0034	.05	
		30		28	70	.1008	.1004	N.C.	N.C.	.498	.497			6.2144	6.2173	.0029	.05	
		31		1	160	.0990	.0988	N.C.	N.C.	.505	.505			6.2629	6.2650	.0021	.03	
		32		1	160	.0988	.1000	+.0012	+1.21	.503	.503			6.1984	6.2003	.0019	.03	
		33		7	160	.0981	.0988	+.0007	+0.71	.504	.504			6.2201	6.2195	-.0006	N.C.	
		34		7	160	.1002	.1004	N.C.	N.C.	.506	.506			6.3243	6.3234	-.0009	N.C.	
		35	JP-4	7	70	.0996	.1002	+.0006	+0.60	.503	.503	N.C.	N.C.	6.2573	6.2616	.0043	.07	N.C.
		36		7	70	.0990	.0993	N.C.	N.C.	.503	.503			6.2262	6.2300	.0048	.08	
		37		28	70	.0988	.1003	+.0015	+1.52	.499	.499			6.1677	6.1722	.0045	.07	
		38		28	70	.1005	.1004	N.C.	N.C.	.505	.505			6.3279	6.3328	.0049	.08	
		39		1	160	.1000	.0999	N.C.	N.C.	.517	.517			6.4347	6.4362	.0015	.02	
		40		1	160	.1000	.0997	N.C.	N.C.	.520	.520			6.4833	6.4899	.0016	.02	
		41		7	160	.0995	.0995	N.C.	N.C.	.507	.507			6.2731	6.2703	-.0028	.04	
		42		7	160	.0993	.0999	N.C.	N.C.	.522	.522			6.5005	6.4995	-.0010	.02	

* N.C. = NO CHANGE

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13. ABSTRACT

The program was conducted in three phases. Phase I, which constituted the major portion of the effort, concentrated on studying 181 style glass fabric reinforced thermoplastic laminates. Phase II investigated the practicality of using graphite reinforcements rather than glass fabric, and finally, Phase III investigated potential methods of production and the cost impact of this concept on component manufacture. It was demonstrated in the program that reinforced thermoplastic laminates could perform competitively with epoxy glass fabric laminates and result in a potentially lower cost production material. The materials were compared on a basis of mechanical properties, environmental resistance and electrical properties. Processing studies showed that the thermoplastic materials could result in substantial manufacturing cost savings through reduced processing time, lower scrappage rate and lower material costs. Cost savings of 35 to 70% were projected for various aircraft components.

DD FORM **1473** 1 NOV 65

D1 4802 1030 ORIG. 3/71
PART 1 OF 3

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	2 T
GLASS FABRIC LAMINATES						
GRAPHITE FIBER COMPOSITES						
THERMOPLASTIC RESINS						
POLYSULFONE RESINS						
PHENOXY RESINS						
ENVIRONMENTAL RESISTANCE						
MECHANICAL PROPERTIES						
CREEP AND FATIGUE PROPERTIES						